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EFFECTIVENESS OF SUSTAINABILITY INCORPORATION IN ENGINEERING CURRICULA

A Framework for Course Design

MAHYUDDIN ARSAT

Effectiveness of Sustainability Incorporation in Engineering Curricula

A Framework for Course Design

PhD Thesis

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Read! In the name of your Lord, Who has created all that exists.

He has created man from a clot.

Read! And your Lord is the most Generous.

Who has taught by the pen.

He has taught man that which he knew not.

(Al – Alaq, 96:1)

Sustainability

is a concept where the **equilibrium state** of three dimensions (environmental, social and economic dimensions) in **indefinite time** and equity between the **intergeneration and intra-generations** are concerned.

Summary

The past decades there has been a lot of discussion on the definitions and principles of the concept of sustainability. The efforts to incorporate sustainability in engineering education have become a point of attention for most universities. Due to the variety of sustainability definitions and principles, sustainability has been interpreted and incorporated in engineering curricula in various ways. In the perspective of Malaysia Higher Education and specifically Universiti Teknologi Malaysia, the efforts to incorporate sustainability in higher education with such varieties are a huge challenge. This study is an effort of the author to face that challenge.

The main objective of this study is to develop a framework for course design to incorporate sustainability in engineering education. To achieve the research objective, the research has adapted several educational research methods into a basic design cycle. The research methods encompass a mixed methods design, a qualitative design and experimental design. The cycle of design for this research was divided into four research phases. The first three phases focus on analysis, design and development, while the final phase deals with implementation and evaluation of the framework.

In research phase 1, the study explores real world practices by reviewing several researches and reports across continents. A total of 26 engineering courses related to sustainability, and 11 concepts and principles of sustainability in engineering education were used as a basis to explore the strategies by several higher institutions incorporating sustainability in engineering education and to understand the concepts of sustainability from engineering education point of view. By employing deductive and inductive analytical techniques, the research outcomes of this phase have contributed two important inputs for the development of the framework. The first input is an element for `contextualizing sustainability´ in engineering education which comprises `approach´, `component´ and `theme´. The second input is an element for structuring courses which comprises `model´ and `orientation´.

In research phase 2, the study highlights positive practices by studying several cases which have been conducted at Universiti Teknologi Malaysia and Aalborg Universitet, Denmark. These cases have provided opportunities for this study to conduct research on 10 sustainability courses and participation of 11 university teachers. Building on the findings from qualitative researches in these two universities, the research outcomes of this phase have contributed to understand how to manage the incorporation of sustainability in engineering curricula and to understand the strategies to incorporate sustainability in course planning.

In research phase 3, the study evaluates several sustainability related engineering courses for the effectiveness. The evaluation for course effectiveness is based on the comparison of teacher´s expectations and students learning outcomes in three aspects, knowledge, skills and attitudes towards sustainability. This study was conducted at Universiti Teknologi Malaysia with participation of three engineering courses. By employing a mixed methods research design, the research outcomes of this phase have contributed to understand the impacts of three engineering courses on students learning outcomes and to identify the factors that contribute to the students learning outcomes. The findings show that there are five elements that can be used as a platform to incorporate sustainability in course planning which are learning

objectives, teaching and learning approaches, learning activities, learning materials and assessment techniques.

In research phase 4, the study validates the proposed framework for course design. The study had been conducted by the participation of university teachers at Universiti Teknologi Malaysia. Based on the teacher´s feedbacks, the framework of course design to incorporate sustainability in engineering education needs to be improved in terms of its presentation and the contents.

As a conclusion, sustainability can be defined as a concept that is concerned on the equilibrium state of the three dimensions (environmental, social and economic) in indefinite time and the equity of inter and intra-generations. The concept suggests the incorporation of sustainability in engineering education should have equal representation of environmental, social and economic dimensions. So that the future engineers are equipped with attributes that contribute to sustainability. Generally, there are five dimensions of sustainability incorporation in engineering curricula which are: model, approach, orientation, theme and component. The dimensions of incorporation provide an overview of higher education practices and understanding of the strategies that have been under taken by universities for this purpose. It shows that contextualizing sustainability into a specific area of learning contributes to the effectiveness of sustainability incorporation.

This study provides evidence supporting the claim of effectiveness of employing student centered learning for sustainability incorporation. Problem-based learning, project-based learning, case-based learning, a competition, an industrial visit, and a community service are the learning approaches represented in this research. The relevant learning activities include peer teaching on thematic topics of sustainability, interviewing sustainability experts, communicating to community of practice, establishing networks with `external´ peers in sustainability, preaching the concepts of sustainability, participating in research development on sustainability, and participating in students´ conference on sustainability. The proposed framework for sustainability incorporation in engineering curricula is suitable both for analyzing existing curricula and development of new educational curricula in engineering.

Sammendrag

I de seneste årtier er bæredygtighedsbegrebet blevet indgående drøftet med hensyn til definitioner og principper. Bestræbelserne på at integrere bæredygtighed i ingeniøruddannelserne er blevet aktuelt for de fleste universiteter. På grund af de mange forskellige definitioner og principper om bæredygtighed har fortolkningen og integreringen af bæredygtighed i ingeniøruddannelsernes studieordninger foregået på forskellig vis. Set fra Malaysias videregående uddannelsers perspektiv og specielt Universiti Teknologi Malaysia, er bestræbelserne på at integrere bæredygtighed i de videregående uddannelser i sådant omfang en stor udfordring. Denne afhandling er forfatterens bestræbelse på at håndtere udfordringen.

Hovedformålet med denne afhandling er at udvikle en guideline for kursusdesign til integrering af bæredygtighed i ingeniøruddannelserne. For at opfylde målet har afhandlingen tilpasset flere pædagogiske forskningsmetoder i en grundlæggende designcyklus. Forskningsmetoderne omfatter mixed methods design, et kvalitativt design og et eksperimentelt design. Designcyklus blev opdelt i fire undersøgelsesfaser. De første tre faser fokuserer på analyse, design og udvikling, mens den sidste fase omhandler implementering og evaluering af guidelinen.

I fase 1 undersøges praksis ved at gennemgå flere afhandlinger og rapporter på tværs af kontinenter. I alt 26 ingeniørmæssige kurser relateret til bæredygtighed og 11 begreber og principper for bæredygtighed indenfor ingeniøruddannelserne er brugt som grundlag for at udforske de strategier, der benyttes af flere videregående uddannelsesinstitutioner til at integrere bæredygtighed i ingeniøruddannelserne, og til at forstå begreberne bæredygtighed fra ingeniøruddannelsens synspunkt. Ved at anvende deduktive og induktive analytiske teknikker har undersøgelsesresultater i denne fase bidraget med to vigtige input til udvikling af guidelinen. Det første input er et element til kontekstualisering af bæredygtighed indenfor ingeniøruddannelserne og omfatter ”strategiske metode”, ”komponent” og ”tema”. Det andet input er en komponent til strukturering af kurser, som omfatter ”model” og ”orientering”.

I fase 2 har afhandlingen belyst positiv praksis gennem en undersøgelse af flere cases på Universiti Teknologi Malaysia og Aalborg Universitet, Danmark. Disse cases har givet mulighed for at undersøge 10 bæredygtighedskurser med deltagelse af 11 universitetsundervisere. Med udgangspunkt i resultaterne fra de kvalitative undersøgelser på disse to universiteter har denne fase bidraget til at forstå, hvordan man kan håndtere integreringen af bæredygtighed i ingeniøruddannelsernes studieordninger og til at forstå strategier til at integrere bæredygtighed i kursusplanlægningen.

I fase 3 har afhandlingen evalueret flere bæredygtighedsrelaterede ingeniørkurser for deres effektivitet. Evalueringen af kursuseffektivitet er baseret på sammenligning af underviserens forventninger og de studerendes læringsresultater i tre aspekter, viden, færdigheder og holdninger til bæredygtighed. Denne undersøgelse blev udført på Universiti Teknologi Malaysia med deltagelse af tre ingeniørkurser. Ved at anvende et mixed methods undersøgelsesdesign har undersøgelsesresultaterne i denne fase bidraget til at forstå virkningerne af ingeniørkurserne på de studerendes læringsresultat, og til at identificere de faktorer, der bidrager til de studerendes læringsresultater. Resultaterne viser, at der er fem elementer, der kan bruges som en platform til at integrere bæredygtighed i kursusplanlægning: Læringsmål, undervisnings- og læringsstrategier, læringsaktiviteter, læringsmaterialer og evalueringsteknikker.

I fase 4 har afhandlingen valideret den foreslåede guideline for kursusdesign. Undersøgelsen blev udført med deltagelse af undervisere på Universiti Teknologi Malaysia. Baseret på undervisernes tilbagemeldinger blev kursusdesignguidelinen til integrering af bæredygtighed i ingeniøruddannelserne forbedret i form af præsentation og indhold.

Som en konklusion kan bæredygtighed defineres som et begreb, der vedrører ligevægtstilstanden af de tre dimensioner (miljømæssig, social og økonomisk) over ubegrænset tid, samt ligelighed mellem og indenfor generationer. Begrebet antyder at integreringen af bæredygtighed i ingeniøruddannelse skulle medføre ligelig repræsentation af miljømæssige, sociale og økonomiske dimensioner, således at fremtidige ingeniører er udstyret med kompetencer, der bidrager til bæredygtighed. Generelt er der fem dimensioner i integrering af bæredygtighed i ingeniøruddannelserne, og de består af ”model”, ”strategisk metode”, ”orientering”, ”tema” og ”komponent”. Disse dimensioner giver et overblik over praksis i højere uddannelser og en forståelse af de strategier, der er blevet benyttet af universiteter til dette formål. Dette viser, at kontekstualisering af bæredygtighed som særskilt læringsområde bidrager til effektiviteten af bæredygtighedsintegrering.

Denne afhandling giver evidens til støtte for påstanden om effektiviteten af at anvende studentercentreret læring for bæredygtighedsintegrering. Problembaseret læring, projektbaseret læring, casebaseret læring, konkurrencer, virksomhedsbesøg, og almennyttigt arbejde er læringsstrategierne repræsenteret i denne sammenhæng. De relevante læringsaktiviteter omfatter peer undervisning om tematiske bæredygtighedsemner, interview med bæredygtighedseksperter, kommunikation til praksisfællesskaber, oprettelse af netværk med ”eksterne” peers indenfor bæredygtighed, formidling af bæredygtighedsbegrebet, deltagelse i udviklingen af bæredygtighedsundersøgelser og deltagelse i studenterkonferencer om bæredygtighed. Den foreslåede guideline for bæredygtighedsintegrering indenfor ingeniøruddannelsernes studieordninger er velegnet for såvel analyse af eksisterende studieordninger som udvikling af nye studieordninger.

Ringkasan

Pada beberapa dekad yang lalu terdapat banyak perbincangan mengenai definisi dan prinsip-prinsip konsep kelestarian. Usaha untuk mengintegrasikan kelestarian dalam pendidikan kejuruteraan telah menjadi tumpuan oleh kebanyakan universiti. Kepelbagaian dalam definisi dan prinsip kelestarian telah membawa kepada kepelbagaian dalam interpretasi dan pengintegrasian dalam kurikulum kejuruteraan. Di dalam perspektif Pendidikan Tinggi Malaysia dan terutamanya di Universiti Teknologi Malaysia, kepelbagaian dalam usaha pengintegrasian kelestarian di pendidikan tinggi adalah satu cabaran yang besar. Oleh itu, kajian ini adalah satu usaha penyelidik untuk berhadapan dengan cabaran tersebut.

Objektif utama kajian ini adalah untuk membangunkan satu kerangka kerja untuk mereka bentuk kursus dalam mengintegrasikan kelestarian di pendidikan kejuruteraan. Untuk mencapai objektif kajian, kajian ini telah mengadaptasi beberapa kaedah penyelidikan pendidikan kepada kitaran asas reka bentuk. Kaedah kajian adalah meliputi reka bentuk kaedah campuran, reka bentuk kajian kualitatif, dan reka bentuk kajian eksperimental. Kitaran reka bentuk untuk kajian ini di pecahkan kepada empat fasa. Pada tiga fasa pertama tertumpu pada analisis, reka bentuk dan pembangunan, manakala pada fasa terakhir meliputi perlaksanaan dan penilaian kerangka kerja tersebut.

Pada fasa yang pertama, kajian ini telah meneroka amalan masa kini melalui sorotan kajian dan laporan-laporan merentas benua. Sejumlah 26 kursus kejuruteraan yang berkaitan kelestarian, dan 11 konsep serta prinsip kelestarian dalam pendidikan kejuruteraan yang menjadi dasar untuk memahami strategi-strategi yang digunakan oleh universiti yang berpengalaman dalam mengintegrasikan kelestarian dan untuk memahami konsep kelestarian daripada sudut pendidikan kejuruteraan. Penggunaan teknik analitis deduktif dan induktif dalam kajian ini telah menyumbang kepada dua input penting dalam pembangunan kerangka kerja. Pertamanya ialah elemen bagi "penerapan kelestarian berdasarkan konteks" dalam pendidikan kejuruteraan yang terdiri daripada pendekatan, komponen dan tema. Keduanya ialah elemen untuk penstrukturan kursus yang terdiri daripada model dan orientasi.

Pada fasa yang kedua, kajian ini telah mempertengahkan amalan-amalan positif menerusi beberapa kajian kes yang dijalankan di Universiti Teknologi Malaysia dan Aalborg Universitet, Denmark. Kajian kes tersebut ini telah memberikan peluang untuk kajian terhadap 10 kursus kelestarian dan penglibatan 11 orang pensyarah universiti. Berdasarkan dapatan kajian kualitatif menerusi dua kajian kes ini, dapatan kajian daripada fasa ini telah menyumbang kepada pemahaman bagaimana pengintegrasian kelestarian ini diuruskan dan pemahaman kepada strategi-strategi pengintegrasian dalam rancangan pengajaran.

Pada fasa yang ketiga, kajian ini telah membuat penilaian dari sudut keberkesanan terhadap beberapa kursus kejuruteraan yang berkaitan kelestarian. Penilaian kursus ini dibuat melalui perbandingan jangkaan pensyarah dan hasil pembelajaran pelajar dari aspek pengetahuan, kemahiran dan juga atitud terhadap kelestarian. Kajian ini telah dijalankan di Universiti Teknologi Malaysia dengan penglibatan tiga kursus kejuruteraan. Dengan menggunakan kaedah penyelidikan campuran, dapatan kajian untuk fasa ini menyumbang kepada pemahaman kesan tiga kursus ini terhadap hasil pembelajaran pelajar. Dalam mengintegrasikan kelestarian di dalam rancangan pengajaran, terdapat lima elemen yang boleh digunakan

sebagai wadah iaitu objektif pembelajaran, pendekatan pengajaran dan pembelajaran, aktiviti-aktiviti pembelajaran, bahan-bahan pengajaran, dan teknik-teknik penilaian.

Pada fasa yang keempat, kajian ini telah membuat prosedur pengesahan terhadap kerangka kerja yang dicadangkan. Kajian ini telah dijalankan menerusi penglibatan pensyarah-pensyarah universiti di Universiti Teknologi Malaysia. Berdasarkan maklum balas daripada pensyarah, kerangka kerja tersebut telah ditambah baik daripada sudut persembahan dan isi kandungannya.

Secara konklusinya, kelestarian boleh didefinisikan sebagai konsep yang mengambil kira keseimbangan pada ketiga-tiga dimensi (alam persekitaran, sosial dan ekonomi) untuk masa yang tiada hadnya dan kesaksamaan antara generasi pada masa kini dan akan datang. Konsep ini menyarankan pengintegrasian kelestarian dalam pendidikan kejuruteraan mestilah menyeimbangkan antara dimensi alam persekitaran, sosial dan ekonomi. Oleh itu, jurutera pada masa hadapan di persedia dengan kualiti-kualiti yang menyumbang kepada kelestarian. Secara umumnya, terdapat lima dimensi dalam pengintegrasian kelestarian dalam pendidikan kejuruteraan iaitu terdiri daripada model, pendekatan, orientasi, tema dan komponen. Dimensi ini memberikan gambaran amalan pendidikan tinggi dan pemahaman terhadap strategi-strategi yang dipraktikkan untuk tujuan tersebut. Ia menunjukkan penerapan kelestarian pada bidang pembelajaran tertentu menyumbang kepada keberkesanan pengintegrasian kelestarian.

Kajian ini telah menyediakan beberapa bukti yang menyokong keberkesanan menggunakan pembelajaran berasaskan pelajar untuk pengintegrasian kelestarian. Pembelajaran berasaskan masalah, pembelajaran berasaskan projek, pembelajaran berasaskan kes, pertandingan, lawatan industri, dan khidmat komuniti adalah bentuk pendekatan pembelajaran yang dibincangkan di dalam penyelidikan ini. Aktiviti-aktiviti pembelajaran yang relevan termasuk pengajaran dalam kalangan rakan sebaya untuk topik bertema kelestarian, membuat temu duga bersama pakar bidang kelestarian, berkomunikasi bersama komuniti, mewujudkan rangkaian bersama rakan sebaya di luar kampus, menyampaikan konsep kelestarian, mengambil bahagian dalam pembangunan penyelidikan dalam bidang kelestarian, dan menyertai persidangan pelajar dalam kelestarian. Kerangka kerja yang dicadangkan untuk pengintegrasian kelestarian dalam kurikulum kejuruteraan adalah bersesuaian untuk menganalisis kurikulum sedia ada dan pembangunan kurikulum pendidikan baharu dalam bidang kejuruteraan.

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Contents

Chapter 1

Introduction

The past two centuries have witnessed enormous development in engineering. Mankind has created the greatest achievement of engineering. We have created automobile, airplane and electronics and we have travelled to the moon. However, there is a dark side to this development. Some historical events of engineering disaster e.g. Chernobyl power plant explosion (1989), Challenger space shuttle explosion (1986), and toxic gas explosion in Bhopal (1984) have impacted not only the world economically and socially but definitely also environmentally. Engineers and their projects primarily aim for the world's development e.g. to provide technological resources; however their engineering activities often contribute to unsustainable world development which includes aspects of environment, social and economy. These negative impacts not only become problems to the current generation but also to the future generation. Therefore it is important to instill engineers with sustainability attributes, where environmental protection, social and economy development become important dimensions in engineering activities. The role of higher institution in educating the future engineers is a great opportunity to make changes for world sustainability.

This chapter introduces the bird's eye view on the concepts of sustainability, the roles of education for sustainability and its impact on the transformation of engineering education. This chapter also brings forward brief discussions on the ever changing practices in higher education for the transformation and the strategies taken to implement the concept of sustainability in engineering education. Towards the end, this chapter highlights the point of departure to carry out the research and this chapter also outlines the overall structure of the whole thesis which includes the research design.

1.1 Sustainability

Sustainability is a concept regarded as confusing and complex by researchers (Bartlett, 1994; Faber, Jorna and Van Engelen, 2005); by definition the concept is regarded as ill defined (Phillis and Andriantiatsaholiniaina, 2001), ubiquitous (Vos, 2007), and contested (Harding, 2006).

Studies on the definition and the concept of sustainability have been carried out by several researchers e.g. Pearce (1988), Costanza and Patten (1995), Lozano (2008) and Moldan, Janoušková, and Hák (2012). The concept of sustainability is often viewed as either an anthropocentric idea (Brundtland, 1987; Brown et al., 1987; and Costanza and Patten, 1995), an eco-centric idea (Bartlett, 1994; Glavič and Lukman, 2001; Vos, 2007; and Lindsey, 2001), or an equilibrium idea (Pearce, 1988; Harding, 2006; Voinov and Farley, 2007; Lozano, 2011; and Moldan, Janoušková, and Hák, 2012). These views on the concept of sustainability interpret the relationships between three major dimensions of the concept differently (environmental, social and economic dimensions). Consequently, the interpretation will define the concept of sustainability and further determine the principles of sustainability in its context.

These three views of the sustainability concept (anthropocentric, eco-centric and equilibrium views) are contradicting one another. An anthropocentric view of the sustainability concept is a view that centralizes the global sustainability to human needs. Sustainability is achieved by accepting human being at the highest level of values and as the most important entity. An eco-centric view on the other hand accepts environment as the highest value compared to other entities and regards the efforts to achieve sustainability can only be by protecting the environment and eliminating environmental pollutions. In contrast, an equilibrium view of sustainability concept accepts all three dimensions of sustainability (environmental, social and economic dimensions) as equal in its value and its significance to global sustainability.

One of the examples of an anthropocentric view on the concept of sustainability can be seen in the concept of sustainable development promoted by the World Commission. According to the definition addressed in the World Commission on Environment and Development report entitled Our Common Future in 1987 (Brundtland, 1987), sustainable development is defined as “the development which meets the needs of the present without compromising the ability of future generations to meet their own needs”. By definition, it would suggest that sustainability should be addressed from the encountered problems of the development, which endangers the human needs in the present and in the future. As mentioned in the report, sustainable development contains two key concepts;

> *“- the concept of needs, in particular the essential needs of the world´s poor, to which overriding priority should be given; and*
>
> *- the idea of limitations imposed by the state of technology and social organization on the environment´s ability to meet present and future needs.”*

Generally the concept of sustainability highlights three major dimensions. The dimensions are environmental, economic and social. Harris (2000) views sustainability as an anthropocentric idea and synthesized the concept into perspectives as:

> *“- a concept that remedies social inequities and environmental damage, while maintaining a sound economic base.*
>
> *- the conservation of natural capital is essential for sustainable economic production and intergenerational equity. Market mechanisms do not operate effectively to conserve natural capital, but tend to deplete and degrade it.*
>
> *- from an ecological perspective, both population and total resource demand must be limited in scale, and the integrity of ecosystems and diversity of species must be maintained.*
>
> *- social equity, the fulfillment of basic health and educational needs, and participatory democracy are crucial elements, and are interrelated with environmental sustainability.”*

Taking the research conducted by Bartlett (1994) as an example of an eco-centric view of the sustainability concept, the research views population as the key problem to unsustainable world. It is highly focus on the impacts of the world population on the consumption of resources, carrying capacity of the ecosystem, environmental pollutions and consumption of non-renewable resources. The research proposed several laws that define the definition of sustainability. An example of the eco-centric view of sustainability can be seen in the seventh law to sustainability, which is outlined as:

> "*Growth in the rate of consumption of a non-renewable resource, such as a fossil fuel, causes a dramatic decrease in the life-expectancy of the resource.*
>
> *i)* *In a world of growing rates of consumption of resources, it is seriously misleading to state the life-expectancy of a nonrenewable resource as `at present rates of consumption´, i.e., with no growth.*
>
> *ii)* *It is intellectually dishonest to advocate growth in the rate of consumption of a nonrenewable resource while, at the same time, reassuring people about how long the resource will last `at present rates of consumption´."* [pp. 22]

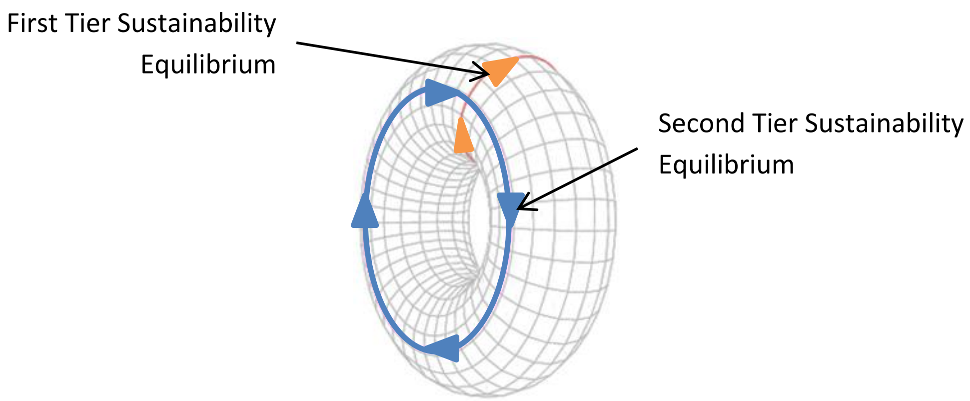

Figure 1.1 Two tiered sustainability equilibria, Lozano (2008)

Above figure illustrates the equilibrium idea of sustainability concept proposed by Lozano (2008). It demonstrates the first tier sustainability equilibrium which is an equilibrium state between environmental, economic and social dimensions and the second tier sustainability equilibrium which is an equilibrium state of time-space (short, long and longer-terms) dimension. This representation promotes a state of sustainability that equally values the three dimensions regardless of time span or in indefinite time. Sustainability (such as living standards, environmental and economic conditions) that might be achieved by today's generation is similar for the future generations.

The discussions of sustainability are not only on the views of the concept and its definition, but also focused on the questions of what the system needs to be sustainable (Voinov and Farley, 2007) and what are the requirements to achieve sustainability (Pezzy, 1992). For example, with regards of the concept of sustainable development, Pezzy (1992) concluded in his work that it is a concept that contains “the same core ethic of intergenerational equity in which future generations are entitled to at least as good a quality of life as we have now”. He added the interpretation of the core ethic is highly dependent on the context. Later in chapter 2, the principles of sustainability and the relationships of the three dimensions are further explained and discussed.

In the effort to educate the future engineers with sustainability attributes, universities and its education systems are one of the platforms which provide opportunities for future engineers to learn the concept and obtain the attributes. However, by the existence of multi views on the concept of sustainability (so far in this chapter three views on the concept are presented briefly), the interpretations of the concept in higher education also vary and depend on the context e.g. disciplines. The learning of sustainability in higher education is interpreted by the sustainability aims or goals (an example of institution interpretation) set by the university and the practices of the community. University teachers design the learning of sustainability solely based on their understanding and experiences in this field. Therefore, the variation on the strategies of incorporation, course structures and course planning in university practices does exist. It is an opportunity to understand and learn the variation in order to understand the role of higher education and engineering education specifically, for sustainability. In the following discussion, this chapter will provide an overview of the incorporation of sustainability in higher education, the efforts taken specifically for engineering education and some of the incorporation strategies in engineering curricula.

1.2 Sustainability in higher education

The importance of education in changing attitudes toward sustainable development has been notified as a part of the World Commission on Environment and Development recommendations for actions. The commission highly depended on public participations, debates and education to start campaigning for sustainable development; and the efforts to promote sustainable development in higher education have been continuously gaining recognitions and participations. According to a research by Segalas (2009) in which the chronology of sustainability in higher education is outlined, the effort towards sustainable development started out before the Brundtland report. It started by adopting in the United Nations Conference on the human environment where the Stockholm Declaration (1972) took place. The events related to sustainability in higher education continue for decades e.g. The Halifax Declaration (1990), Thessaloniki Declaration (1997), World Declaration on Higher Education for the 21st Century and Framework for Priority Action for Change and Development in Higher Education (1998) and The Barcelona Declaration (2004). It (the events) provides a platform for universities and other organizations to change their opinions and deepen their understanding on the issues of sustainability and the role of university towards global sustainability. The declarations are outlined as guidance and principles for universities, demands commitment from the signatory universities and organizations in taking actions in transforming the role of university as a part of the efforts for global sustainability.

Transforming higher education curricula for sustainable development is a challenge to curriculum developer and course designer (Allen et al., 2009). They have to deal with the complexity of sustainability concept and the existing curriculum in higher education. Despite the challenge and higher demand on sustainability in tertiary levels, many universities worldwide have included sustainability in their programs. According to Kitamura and Hoshii (2006), universities in Japan have initiated effort to promote Education for Sustainable Development (ESD) as a part of education transformation in higher education and the establishment of programs is formally outlined by Japan´s Action Plan in 2006. The education transformation manifested three types of ESD curricula at undergraduate level which are;

i) Part of liberal arts and professional courses
ii) Newly formulated or existing course as minor course
iii) Establishment of ESD-related departments

Chhokar (2010) had explained the implementation of the Decade of Education for Sustainable Development (DESD) in India that has been enforced to the Ministry of Human Resources Development (MHRD). Education in India especially higher education has transformed in many different ways on implementing a variety of courses and programs. The transformation is demonstrated by the existence of new special programs (such as Master in Sustainable Development), sustainability components have been introduced into existing programs and various courses and modules related to sustainability have been included in a wide range of disciplines. It is also important to acknowledge efforts of education transformation for sustainable development at University of Cambridge reported by Fenner *et al.* (2005). For example one of the divisions has integrated sustainability by introducing sustainability thinking into undergraduate teaching and has offered a Master of Philosophy degree in Engineering for Sustainable Development. In another research by Holmberg *et al. (*2008), three European universities have strategized their effort of education transformation with insertion of compulsory courses in traditional courses, new programs on SD, minor specializations for undergraduate and master degree. In the study by Murphy *et al.* (2009), SD has been extensively incorporated at engineering programs in U. S. universities. Four main strategies were used to transform their courses and course modules to develop dedicated SD courses, integrate sustainable engineering concepts into traditional courses, specific topic on sustainable technologies and interdisciplinary courses.

Interestingly the changes have been made regardless of the evolving meaning of SD, broad and comprehensive concept of sustainability as well as the overcrowded of the existing engineering curricular. All these changes in engineering education across universities around the world for the past decade or more have to be measured and the effectiveness of the sustainability incorporation in engineering education has to be seen as part of the changes. Therefore the aim of engineering education to provide future engineers with sustainability attributes can be achieved, and eventually contribute to the world sustainability.

1.3 Sustainability in Engineering Education

Sustainability in engineering education is a concern across countries. The debate on sustainability and the human impacts on the environmental are at the heart of the current development. Sustainability is becoming more important to engineering education; the roles of current engineers are more beyond technology. The roles in which De Graaff *et al.* (2001) in their study described that the engineers have to be fully aware not only on technological aspects but should have the ability to deal with societal aspects of technological innovations. Gough and Scott (2007) pointed out their views by stating that the world today is to a high extend relying to technology and the human race is using technology from early morning until late night. Therefore technology cannot be deployed as if it had no environmental or societal implications. Engineers, must therefore be a key player in sustainable development, and have an obligation as citizens and not just act as isolated technical experts. The UK Royal Academy of Engineering, which started to develop Principles of Engineering Design Scheme in 1989, pointed out that achieving sustainability, will require some significant shifts in behaviors and consumption patterns. Often it will be – and should be – engineers who are in need of making decisions about the use of material, energy and water resources, the development of infrastructure, the design of new products and so on. However, engineers must recognize and exercise their responsibility to society as a whole, which may sometimes conflict with their responsibility to the immediate client or customer.

The necessity of sustainability in engineering education has been discussed in the study by Taoussanidis and Antoniadou (2006) into several perspectives. First, the involvement, roles and activities of engineers that drive the industries and economy will strongly affect the unsustainable economy. Therefore, most of unsustainable effects are frequently blamed on engineers as their activities rooted in industries. Second, engineering education has to comply with the social expectations and pressures towards internationalization and globalization. Owing to the expectations, engineering education needs a transformation in terms of programs and curricula that are aligned with international standards and accredited for internationalization in which sustainability is a part of the criteria. Third, the movement of engineering profession from largely as a part of public organizations into a fully private company, especially in context of European engineering employment, whereby engineers have to deal with different kind of situations where non-technical skills e.g. management skills and financing skill are needed. Lastly, many of government and private sectors nowadays are committed to implement sustainability in their engineering practices. The hiring requirements are changing according to the sectors expectations; as a result engineers have to prepare themselves with attributes towards sustainability.

Furthermore, engineering education can serve as a suitable platform to develop relationships between university and industries to explore the link between sustainability, engineering skills and educational programs. Through engineering education, sustainable development can be embedded from the very beginning at undergraduate level. For example, based on a National Report of Malaysia (1998) entitled The Development of Education, Malaysia started their effort on education for sustainable development in particular related to the environmental aspects, by implementing it across the curriculum at school level. The Malaysian Ministry of Education has developed the environmental education curriculum called Environmental Education Curriculum Guidelines. However, sustainability in higher education in Malaysia had started with various way of implementation. For example, Agamuthu and Hansen (2007) said, in several years from 1998 to 2006, Malaysian – Danish universities conducted activities to develop skills and knowledge for environmental engineering and management. The implementation of sustainability in higher education and its recognition are also demonstrated in a report by Five Years of Regional Centres of Expertise on ESD (2005), where Universiti Sains Malaysia has been appointed as one of the United Nations` Regional Centre of Expertise (RCE) on Education for Sustainable Development in conjunction with the United Nations Decade on Education for Sustainable Development.

Sustainability in engineering education is not limited to the incorporation of the concept into the curriculum but also reaching to the field of engineering researches. For instance, approximately a quarter of a billion dollars of research funds has been allocated for engineering research related to sustainability for several universities in the US (Murphy, 2009). Most of the researches focus on the themes such as `energy and power generation´, `life cycle assessment´, `water´, `industrial processes´, and `pollution prevention, fate and transport´. Murphy (2009) has identified that the researches are carried out 1) *"to evaluate or improve an existing infrastructure or industry sector,* 2) *to develop technology that facilitates sustainable behavior and systems,* 3) *to address complex systems interdisciplinary,* 4) *to develop and optimize a sustainable engineering tool"*. In other cases, the researches on sustainability are not only conducted for the purpose of creating technological innovations, but they also have brought the research to the outside community or to the public. Beach *et al.* (2007) demonstrated an outreach program based on a water treatment project developed by engineering students. The project, which was funded by Schlumberger Excellence in Educational Development (SEED) Foundation, has developed an educational tool. A tool that is called SEED Water Project kit has been distributed to over 300 schools in Houston, Texas. The partnership between school and university provides opportunity for engineering students to gain knowledge and skills not only from the engineering project itself, but also from the community.

Engineers Without Borders (EWB) is one of educational models that highlights the development of *"technical capacity at the local level in developing countries to ensure the development is generated innovatively, appropriate and sustainable, and available at the local level"* (Johnstan, Caswell and Armitage, 2007). It is one of the outreach programs conducted by universities for engineering students around the globe (EWB projects e.g. Smith, Brown and Cahill, 2009 and Amadei, ASCE and Sandekian, 2010). In Canada, the project under EWB has been conducted at the local level and international level. Through the EWB projects and the problem-solving processes, the study of Johnstan, Caswell and Armitage (2007) concluded that nearly 70% of participated engineering students have improved their social and environmental awareness. The study pointed out that the awareness on the social and environmental aspects amongst engineering students can be developed by participating in a real world project.

1.4 Strategies of sustainability incorporation in engineering curricula

In context of sustainability incorporation in the existing engineering curricula, Salih (2008) recognized two kinds of models of sustainability courses, the stand alone subject model and the embedded model. Both models aim to implement sustainable development through the use of soft skills among Malaysian undergraduate students. In this study, the stand alone subject model is regarded as a model that "uses the approach of training and providing opportunities to student to develop soft skills through specific courses that are carefully planned for this purpose". Furthermore, most of the courses that have this profile are usually a part of the program either as a compulsory course or elective course for instance an entrepreneurship course and critical thinking course. She added the stand alone subject model can also be manifested as a minor course; from the collection of several additional stand-alone courses. On the other hand, Salih (2008) explained that embedded model "uses the approach of embedding the soft skills in the teaching and learning activities across the curriculum". The intended soft skills will be integrated with the existing learning objectives, which means that the original learning objectives can be maintained.

Segalas (2009) stipulated that sustainability can be incorporated in engineering education curriculum in four different ways; compulsory courses, minor courses, introduction sustainability in the final year project, and intertwining sustainable development in all courses. He concluded in his finding that embedding sustainability into the existing engineering curricula is the most difficult approach to implement. It is often related to the strengths, weaknesses, opportunities and threats of curriculum change for sustainability in engineering education. He classified the factors as follows.

The internal factors that contribute to the change of engineering education towards sustainability can be divided into two factors, which are the strengths and the weaknesses of the institutions.

Strengths

i. *Leadership*
ii. *Innovators/Champions*
iii. *Internal networks*
iv. *Small size*
v. *Coordination unit*
vi. *Increase of active learning*

Weaknesses

i. *Academic freedom*
ii. *Incentive structure*
iii. *Conservative administration*
iv. *Disciplinary oriented*
v. *Resistance to change*
vi. *Staff lack of comprehensive SD*
vii. *Overcrowded curriculum*

The external factors on the other hand, can be divided into opportunities and threats.

Opportunities

i. *Benchmarking from peer institutions*
ii. *Sources of funding available*
iii. *Pressure from accreditation agencies*
iv. *EHEA*
v. *ESD HEI networks*

Threats

i. *Lack of pressure from society*
ii. *Lack of pressure from employers*

Based on these two studies as well as the studies that have been explained earlier, the researcher could pre-determine that there are two models of sustainability course. The first is called a stand-alone model and the second is called an integrated model. Table 1.1 depicts a basic structure of a sustainability course merged from the studies. The profile of both models will be further developed and explained in chapter five. Although this profile and its characteristics permit sustainability incorporation, both models have its pros and contras. According to Salih (2008), because of its capacity to provide specific knowledge and specifically design for its purposes, stand-alone model is more favorable in terms of course planning and implementation. As the down side, the stand alone model has constraints for interdisciplinary and cross disciplines.

The integrated model on the other hand gives more challenges when it comes to course planning and implementation. Because of the availability for interdisciplinary and cross disciplines, the model demands a high collaboration between teachers and schools. In fact, by integrating additional learning objectives with the existing learning objectives, teachers have to master the additional knowledge e.g. fundamental knowledge of sustainability, and have to connect the knowledge to the existing knowledge.

Table 1.1 Basic structure of sustainability courses

Study	Course structure	
	Stand-alone model	Integrated model
Kitamura and Hoshii (2006)	Newly formulated or existing course as a minor course	Part of the existing course
Salih (2008)	Stand alone subject model	Embedded model
Holmberg (2008)	New minor course	
Segalas (2009)	Compulsory course	Integrated in final year project
	Minor course	Intertwined in all courses
Murphy (2009)	Dedicated SD course	Integrated as topic
Chhokar (2010)		Integrated modules/courses

In general, both models are widely used in universities around the globe. Some universities prefer to incorporate sustainability by adopting the stand alone model, some favor the integrated model as an approach to embed the concept to the engineering programs and some strategically combine both models. With the variety of practices, the effects of each model towards learning sustainability and its effectiveness on achieving learning objectives are taken as points of departure to carry out the research. In addition to that, when the effectiveness of sustainability incorporation is identified, this also leads to the effort of developing a framework of course design that aims to incorporate sustainability into the existing engineering curricula.

1.5 Effectiveness

In a basic design cycle, evaluation is the final process that sorts out the effectiveness and the defects of the design. Basically there are two kinds of method for an evaluation, a product evaluation and a process evaluation. In a curriculum design, formative and summative evaluations are possible forms of evaluations that can be applied in evaluating the curriculum.

Evaluating the effectiveness requires some sort of indicators that are able to indicate the effectiveness of sustainability incorporation. The indicators have to be developed based on clear definition, principles and guidelines of sustainability. Previous work has discussed a few findings on policies, principles, indicators and guidelines to develop sustainability in engineering education.

The question that arises is how the effectiveness of the sustainability incorporation can be measured? For this purpose, researcher has defined effectiveness of sustainability incorporation as the capability to provide a sufficient requirement to achieve the targets or goals. In practice, the targets or goals of the course can be identified by the learning objectives that have been planned by the course developer. Therefore, as illustrated in Figure 1.2, the capability of the course to provide the sufficient requirement can be measured by evaluating the students learning outcomes and comparing them to the learning objectives. For this purpose, the researcher has categorized student´s learning outcomes into three elements; knowledge, skills and attitude.

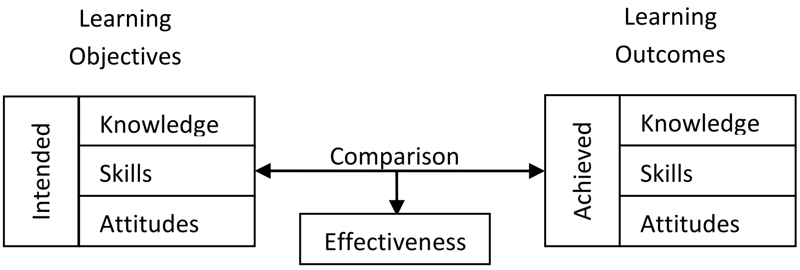

Figure 1.2: Strategy of evaluating effectiveness

1.6 Research objectives

The objectives of this research are as below:

i) To develop a design framework for incorporating sustainability in engineering curricula.
ii) To contribute to Malaysian Higher Education for sustainability incorporation.

1.7 Research questions

The overall research question is how to incorporate sustainability in engineering curricula.

There are several research questions have to be answered in order to address the overall research question as well as to achieve the research objectives. The research questions for this study are:

i) What is the current practice of the sustainability integration in engineering curricula?

ii) What are the considerations taken by the studied universities to incorporate sustainability in engineering curricula?

iii) What is the effectiveness of the cases in terms of knowledge, skills and attitudes?

iv) What are characteristics of effective sustainability incorporation in engineering curricula presented in different universities?

1.8 Conceptual framework

The following figure illustrates a conceptual framework that guides concept exploration paths, and identifies research variables and interconnection of the concepts. Basically, the figure represents the path of concept exploration, from the most outer layer into the core of the circle. It begins with exploring the concepts of sustainability and the connections to the concepts of sustainability in engineering education. In the third layer, four main concepts of sustainability integration in engineering curricula are presented. The concepts are themes, models, orientations and approaches. These concepts are conceptually interconnected with competencies of sustainability. It is a set of fifteen sustainability competencies that will be further discussed in chapter four. The sustainability competencies in this research are attributed as students learning outcomes: knowledge, skills and attitudes. Measuring those elements would define the effectiveness of the incorporation.

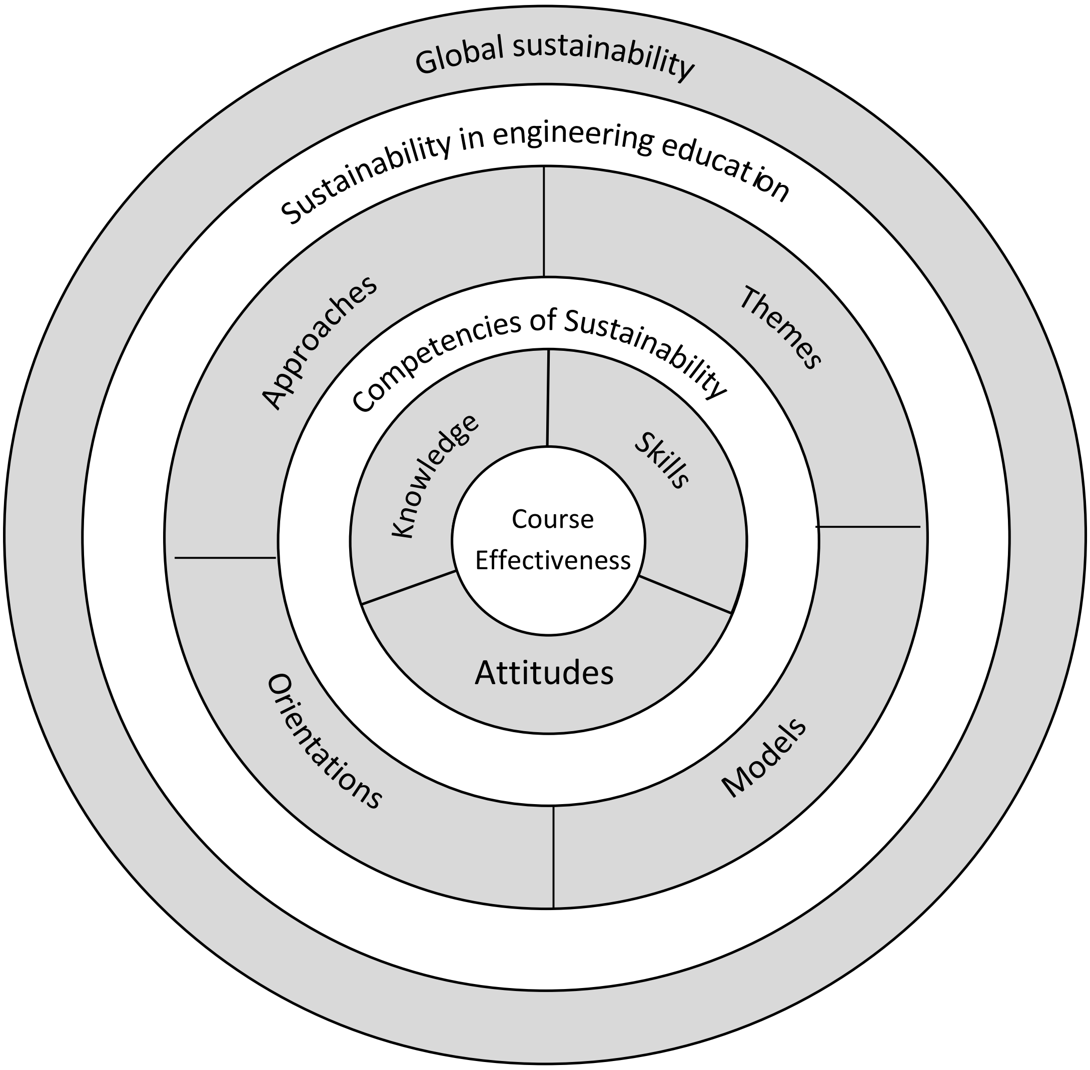

Figure 1.3 Conceptual framework

1.9 Research methodology

<table>
<tr><th>Phase</th><th>One
Exploring real world practices</th><th>Two
Highlighting positive practices</th><th>Three
Evaluating course effectiveness</th><th>Four
Validating design framework</th></tr>
<tr><td rowspan="4">Research purpose</td><td colspan="2">Exploration</td><td></td><td rowspan="4">Validation</td></tr>
<tr><td></td><td colspan="2">Description</td></tr>
<tr><td></td><td></td><td>Explanation</td></tr>
<tr><td colspan="3">Design and Development</td></tr>
<tr><td>Research design</td><td>Exploratory mixed methods</td><td>Qualitative</td><td>Triangulation mixed methods</td><td>Qualitative</td></tr>
<tr><td>Data collection technique</td><td>Document analysis
Ranking task
Interview</td><td>Document analysis
Interview</td><td>Conceptual Maps
Procedural Diagram
Questionnaires</td><td>Open-ended questions</td></tr>
<tr><td>Research question</td><td>Research question 1</td><td>Research question 2</td><td>Research question 3 and 4</td><td>Overall research question</td></tr>
</table>

Figure 1.4 Overall research methodologies

Due to the aims to develop a framework and contribute to Malaysian Higher Education for sustainability incorporation, this study has employed a basic cycle of design into the overall research methodology (see chapter 3 for further explanations). Therefore, the development of the framework is based on the research findings from each phase. The research consists of four phases. Phase one: exploring real world practices, phase two: highlighting positive practices, phase three: evaluating course effectiveness and phase four: validating design framework.

By adapting a basic design cycle, the outcomes from each of the phases are fed as inputs for the next phase. The outcomes are also very important to establish understanding of the overall research, consequently the understanding gained by phases. It is like a pyramid of understanding. Figure 1.4 depicts the alignment of the research purposes, research designs, data collection techniques and research questions. This study employs exploratory mixed methods to design the methods for the exploration of real world practices. This phase requires document analysis, ranking task and interview to collect the data and answer research question 1.

In phase 2, two universities were selected as examples in order to understand deeply the designing and the implementation parts of sustainability incorporation. By conducting document analysis and interview sessions on the selected cases, research question 2 was answered. Three selected sustainability courses have participated in phase three. In this phase conceptual maps have been used as a tool to measure knowledge of sustainability. It is a tool that has been tested by several researchers in previous studies. The other two instruments were procedural diagram and survey to measure skills and attitudes. Finally in phase four, the proposed framework was tested where the results address the overall research question.

1.10 Scope and limitations of works

This research project explores concepts and principles of sustainability in engineering education as well as the models of the course design and the implementation of education about sustainability in engineering education from several universities. The exploration is limited to several accessible publications and documents as most of the publications and documents are open access and accessible for researcher. The exploration also included teachers' and experts´ feedbacks from several universities and continents.

For further understanding on the models and the implementations, the project has been strategically divided into several case studies. The case studies were planned and undergone in two universities, which are Universiti Teknologi Malaysia in Malaysia and Aalborg Universitet in Denmark. Several engineering courses in both universities have been selected for in-depth studies where the limitation of documents are very minimum, most of data related to courses and programs are more accessible and teachers´ feedbacks are more transparent.

In the evaluation works, the study focuses on four courses offered in Universiti Teknologi Malaysia. The courses were selected as they were offered on the semester where the evaluation works were planned. As depicted in Figure 1.5, the evaluation works were carried out by measuring three major elements of learning, knowledge, skills and attitudes.

Finally, the emerged outcomes contributed to the development of a framework for the course design. The framework includes the findings from the exploration works, the case studies and the evaluation works. The proposed framework is also limited to the Malaysian context and to some extend it could work for other universities.

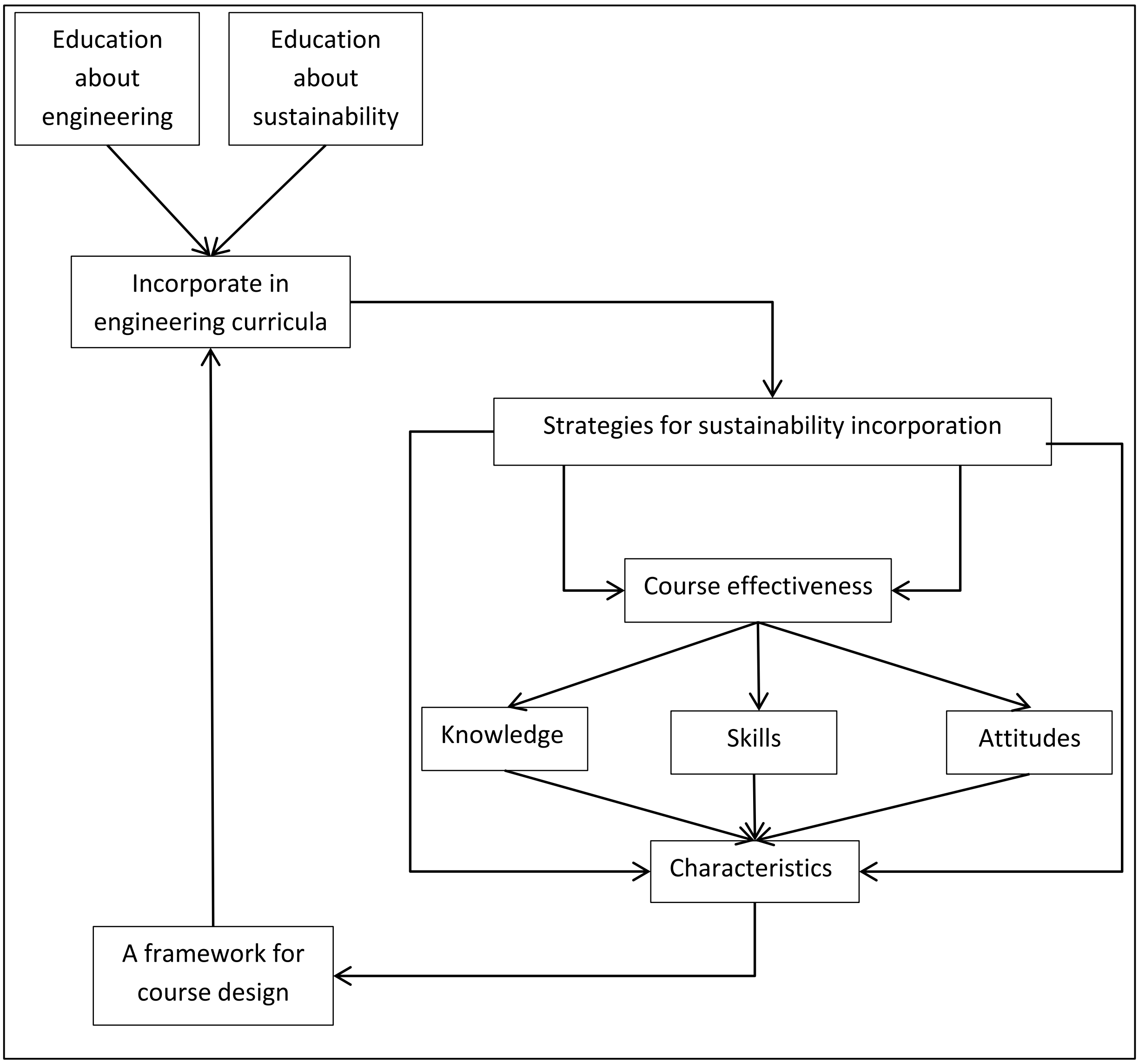

Figure 1.5: Diagram of research focus

1.11 Thesis outline

The thesis is documented into ten chapters. The chapters (chapter 1 and chapter 2) have been organized so that it could provide theories and discourses on sustainability and related to the research. Chapter 3 provides research methodology and justification on the research design. For chapter 4 until chapter 9, the chapters have been organized by adapting the research design process presented in the research methodology chapter. The chapters do not only report the activities but also detail out the research methods, present research outcomes and reflect the activities. The overall reflections on the research and conclusion are documented in chapter 10. The details of the chapters can be translated as follows:

Chapter 1 – Introduction

- Provides an overview of the research and determines the research topic and research questions

Chapter 2 – Literature review

- Provides a discourse on sustainability in terms of its definition, concepts and principles
- Provides a discourse on sustainability in higher education related to the implementation of sustainability concept in universities
- Provides a discourse on the needs of sustainability in engineering education
- Explores the theories on models of curriculum design
- Explores the strategies to incorporate sustainability in curriculum

Chapter 3 – Research methodology

- Outlines/presents the research methodology including research worldview, research design, data collection techniques and alignment on research questions

Chapter 4 – Development of research instruments

- Determines methods and tools for data collections in each research phase
- Develops research instruments for each research phase
- Defines analysis techniques

Chapter 5 – Phase one: Exploring real world practices

- Establishes a profile of the stand-alone model and the integrated model
- Explores other strategies in relation to designing sustainability course in engineering education
- Explores concepts and principles of sustainability in engineering education
- Defines sustainability competencies for engineering education

Chapter 6 – Phase two: Highlighting positive practices

- Highlights teacher´s experiences integrating sustainability in engineering curricula
- Highlight teacher´s experiences in course planning
- Highlight teacher´s experiences implementing the courses

Chapter 7 – Phase three: Evaluating course effectiveness

- Evaluates the effectiveness of sustainability incorporation in three courses
- Analyzes and indicates the effectiveness in terms of sustainability knowledge, skills and attitudes
- Analyzes the factors that contribute to the effectiveness

Chapter 8 – Phase four: Validating design framework

- Validates the framework from teacher´s perspectives
- Analyzes the deliverability and practicality aspects of the framework

Chapter 9 – Conclusion and recommendations

- Provides overall reflections on the research activities and drawing conclusion

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Chapter 2

Sustainability in Engineering Education: unraveling the concept

2.1 Introduction

This chapter presents the state of the art of sustainability in engineering education, including a discussion on the transformative phase of higher education towards sustainability, the discourse on the concepts and principles, strategies of implementations, models and principles of curriculum design. It aims to provide understanding on the body of knowledge that is significant to address the research questions and the research objectives. It is also written to address the importance of the research and the contribution of the research to the field of sustainability in engineering education.

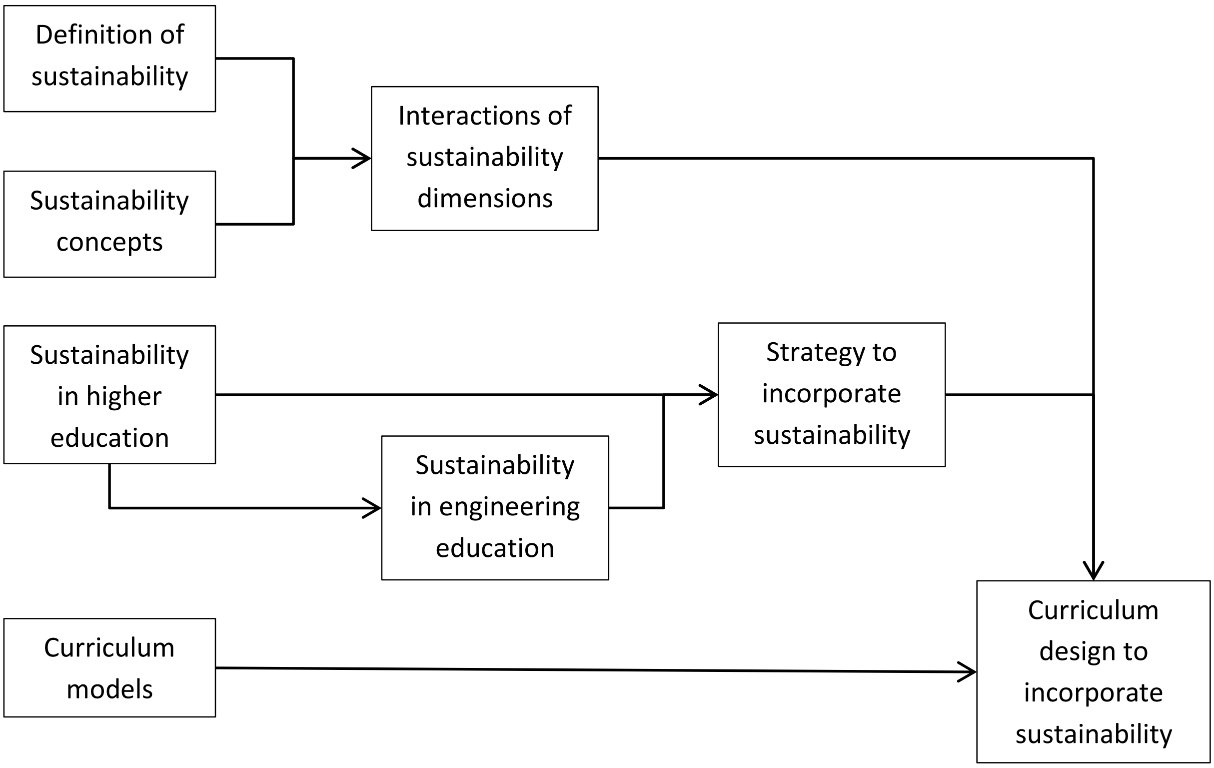

Figure 2.1 Discussion paths for Chapter 2

2.2 Definition of sustainability

Building on the systemic approach of past researches, sustainability and sustainable development have been defined from the understanding on what the system needs to sustain and for how long the system needs to be sustained. In terms of the definition of sustainability this study chooses the standpoint that it is the state where economic, environment and social dimensions are equally sustained in the highest level of system that is called as "super system". In a super system, sustainability is considered indefinite or forever whereby in a lower system, sustainability is restricted to some period of time (definite). In addition, sustainability also has been defined as a concept that considers the equity of the current and the future generations. The definitions of sustainability will be further discussed and briefly analyzed in this chapter. The discussions are presented from the common points of view on the concept of sustainability which comprises anthropocentric, eco-centric and equilibrium views, and highlights in terms of time-space either as an indefinite system or a definite system.

In the well-known report by Brundtland (1987), sustainable development has been defined as a *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs".* It is evidence that sustainability has been defined as anthropocentric idea where human beings are the final aim and viewing sustainability in terms of human values. In the same view on sustainability, Brown et al. (1987) highlights in their study, to define sustainability, the human survival is the key system to be sustained where the study stated that *"most definitions* (in their study) *state or imply that the goal of sustainability is human survival and do not accept the desirability of a sustainable biosphere without the existing of homo sapiens."* Developing from the study of several researches, Brown et al. (1987) found that the common themes used to define sustainability are:

- *i.* *Continued support of human life on earth*
- *ii.* *Long term maintenance of the stock of biological resources and the productivity of agricultural systems*
- *iii.* *Stable human population*
- *iv.* *Limited growth economies*
- *v.* *An emphasis on small-scale and self-reliance*
- *vi.* *Continued quality in the environment and eco-systems*

By accepting the anthropocentric view on sustainability and its indefinite characteristic, the definition of sustainability can be made including the social or cultural dimension emphasizing quality of life, the dimension of economy emphasizing on steady-state economy and the biological dimension emphasizing maintenance and management for the survival of species and ecosystems.

In a similar view on sustainability, Costanza and Patten (1995) interpreted sustainability as a system that has the ability to survive and persist which is pointed as the basic idea of sustainability. They have added that a system can be viewed as a nested hierarchy of systems. The system for the concept of sustainability is mostly related to the global socioeconomic system. In the case of Pezzy (1989) and Costanza (1991), as mentioned in the study of Costanza and Patten (1995), most definition of sustainable development includes:

i. *A sustainable scale of economy, relative to its ecological life-support system*
ii. *An equitable distribution of resources and opportunities between present and future generations.*
iii. *An efficient allocation of resources that adequately accounts for natural capital*

The study also argues that the systems have a limit of time; the survival of the systems is not indefinite. The longevity of the systems is expected to depend on the longevity of subsystems.

By translating the aims of the sustainability principles proposed by Lindsey (2011), sustainability is viewed as an anthropocentric idea. The author envisions that the proposed principles can lead to enhanced utilization of resources in the life cycle for all components in the systems, so that the sustainability of ecosystems, human resources, production capabilities and community resources can be improved. However, the proposed principles are considerably to be leaning to the eco-centric view of sustainability. The principles were developed from the main key factor of wastefulness where sustainability can be achieved by reducing waste in human activities, man-made technology, and systems.

Bartlett (1994) attempted to define sustainability more concretely by focusing on the issues of population and its relation to the environmental dimension such as agriculture activities, resources consumptions and goods (an eco-centric view). His definition of sustainability is built on the proposed laws, hypotheses, observation and predictions related to sustainability. For instance, he proposed with respect to the laws of sustainability that population growth is the root cause of an unsustainable world, a larger population is a hurdle to sustainability, prolong the availability for nonrenewable resources by improving technology, technology for energy efficiency promotes increment in the number of resources needed, pollution rates less than natural cleansing capacity can lead to sustainability, and unsustainable world will stop population growth.

Another eco-centric view on the definition of sustainability has been highlighted in the study of Glavič and Lukman (2001). By focusing on the environmental engineering field, the definition of sustainability term e.g. supply chain management and voluntary environmental agreement, is presented in the hierarchy representation. In the form of pyramid, the sustainability terms have been defined and categorized into several classifications which are principles, approaches, sub-systems, sustainable systems and sustainable policy classes. The study also defined sustainable development as the evolution of human point of view to a “responsible” economical perspective that is in harmony with natural processes and environmental.

Without neglecting the existing three dominant dimensions in the concept of sustainability, Vos (2007) defined the definition of sustainability in `thickness´ dimension. For instance, the thickness of sustainability is defined in terms of the ontology nature. The sustainability is considered as extremely thick (far end of the continuum) if the entire natural capital is seen as intrinsically valuable. Whereby, the thin version of sustainability would express only some of the natural capital that is seen as intrinsically valuable. Similarly, the thickness of sustainability is implied to economic and social dimensions. The study also highlights the common elements that define sustainability. It is defined by "looking at environmental problems in relation to the economy and society", the interconnections of three major dimensions and intergenerational equity.

Other than anthropocentric and eco-centric views on the definition of sustainability, sustainability also has been defined in the equilibrium perspective. It is a perspective viewing economic, environmental and social dimensions as fairly important to achieve sustainability. Pearce (1988) elaborated the meaning of sustainability as *"making things last, making them permanent and durable. What is being sustained can be an object of choice – an economy, a culture, an ethnic grouping, an industry, an ecosystem or sets of ecosystems – but sustainable development implies that the object of concern is the whole process of economic progress in which economy contributes to improvement in human welfare…"* He added that *"sustainability either means sustaining and augmenting natural environmental systems, or is a condition for sustaining economic development".* He pointed out that sustainable development is also an interpretation of natural resources in economic perspective i.e. stock of natural capital. To achieve sustainability, it requires a constant asset of natural capital which includes *i) justice in respect of the socially disadvantaged, ii) justice to future generations, iii) justice to nature, and iv) aversion to risk arising from:*

- *our ignorance about the nature of the interactions between environment, economy and society,*
- *the social and economic damage arising from low margins of resilience to external `shock´.*

Harding (2006) highlights his equilibrium view on the concept of sustainability by stating that,

> *"Regardless of the range of definitions of sustainability…., and lack of agreement over the interpretation of the concept, there seems to be a general agreement that it involves simultaneous satisfaction of economic, environmental and social factors. Meeting environmental criteria in a society which fails to meet economic and social goal concerning justice and equity does not make for sustainability". [pp. 233]*

It is agreed that sustainability is referring to the ultimate destination or goal and sustainable development is a process that guides to achieve the destination. The study argued that the concept of sustainability is entirely depending on the individual world views and values. Therefore, it is an individual decision on what is the ultimate goal (system need to be sustained) and how to achieve it.

According to Voinov and Farley (2007), it is highly crucial to determine what is needed to be sustainable and for how long it is needed to be sustained. They argued that by prolonging the sustainability of a system at a particular level of ecosystem hierarchy, it may deteriorate the sustainability of other levels. In other words, the global sustainability (top level of ecosystem) might get undermined if the local or regional sustainability (lower level of ecosystem) is extended for too long. They elaborated,

> *"…. in most cases sustainability can be ensured only by borrowing energy, resources (capital) and adaptive potential from outside of the system, or by decreasing the sustainability of the global system. Sustainability of a subsystem is achieved only at the*

expense of the super-system or other subsystems. Therefore the institutions and organizations are to emphasize the global priorities and first of all test policies and strategies against the sustainability of the biosphere and of humanity as a whole, rather than the regional or local interest of stakeholders, representing particular localities, communities, district or countries" [pp. 111]

The study also pointed out that in order to achieve sustainability there is a limit of time for sustaining a system before it requires changes for adaptation or even destruction. They concluded, *"sustainability is not about a lack of change. Rather, it is about appropriate rates of change for different levels in a system hierarchy"*.

In the effort of envisioning sustainability in a three-dimensional model, Lozano (2008) presented the concept of sustainability into the perspective of equilibrium. The study envisioned sustainability by combining three pillars which are economic, social and environmental dimensions and the temporal dimension to attain equilibrium. In his study, the definition of sustainability has been categorized into five perspectives. The perspectives are:

i) *Conventional economists´ perspective*
- *A steady state and efficient economy*
- *Sees sustainable development as an element of development path*
- *Neglecting impacts of economic activities upon social and environmental aspects*
- *Neglecting impacts of economic activities upon the future*

ii) *Non-environmental degradation perspective*
- *Impact of economic activities on the environment is the focus*
- *Protecting environment and natural resources*
- *Eliminates indefinite consumption on natural resources*
- *No depletion on environmental capital*

iii) *Integrational perspective (encompasses economic, social and environmental aspects)*
- *Integrating the three pillars and its relations*
- *Lacks of continuity and focuses on the current activities*

iv) *Inter-generational perspective*
- *Considering current, short term and long term effects*

v) *The holistic perspective*
- *Combining integrational and inter-generational perspectives*

Moldan, Janoušková, and Hák (2012) scrutinized the definitions of sustainability based on the concept of economic sustainability, social sustainability and environmental sustainability. The study has analyzed the concepts from the perspectives of Brundtland (1987) and Rio Declaration (1992). The concept of sustainable development has been interpreted as a pragmatic and an anthropocentric idea. It clearly puts the social sustainability (where the documents highlight the people's well-being and needs) as the main focus of the concept of sustainable development. Referring to Maslow´s pyramid, the study stated that in order to achieve sustainability, human have to attain unselfish behavior, by which the satisfaction of physiology, survival, safety, love and esteem are fulfilled beforehand. The concept also suggests an integration of human, economic activities and nature and concerns on the current and future generations.

Table 2.1 Analysis of sustainability definitions

Authors	View			Time - space	
	Anthropocentric	Eco-centric	Equilibrium	Indefinite	Finite
Brundtland (1987)	x				x
Brown et al. (1987)	x			x	
Pearce (1988)			X	x	
Bartlett (1994)		x		-	-
Costanza and Patten (1995)	x				x
Glavič and Lukman (2001)		x		-	-
Harding (2006)			X	-	-
Voinov and Farley (2007)			X	x	x
Vos (2007)		x		x	
Lozano (2008)			X	x	
Lindsey (2011)		x			x
Moldan, Janoušková, and Hák (2012)			X		

Table 2.1 demonstrates the analysis of sustainability definitions presented in several studies from the year 1987 until 2012 into five categories, which focuses on the views and time-space of the definitions. It is a part of the evidences to the vast interpretation towards the concept of sustainability. The view of sustainability evolved from solely defined as an anthropocentric idea into eco-centric and equilibrium concepts. By viewing world as a supersystem and regional or local area as a system, the concept has been defined in systems view. The table also shows the inconsistent stands on the issues of how long the sustainability is taken (time-space); either it is an indefinite system or a definite system. Therefore, it is important to establish definition of sustainability in this study so that discussions on the concept of sustainability either in general context or in engineering education is interpreted precisely aligned with the original intention.

Sustainability is widely accepted as a concept that consists of three key dimensions which are environmental, social and economic dimensions. Each of the dimensions have been mentioned and explained in the presented studies. The overview shows that the impact of the three dimensions is being contested. Each of the dimensions earned dissimilar merit or weight in different studies and cases. Some of the studies give a huge weight to the environmental dimension compared to the other two dimensions. For other studies, the environmental dimension is not a major focus compared to the social dimension. The study also showed that, the difference in terms of the unbalanced merit of the three dimensions is due to the fact that each of the fields, disciplines, studies and cases faces different kind of needs in order to achieve sustainability. It is believed that, in cases where a particular dimension of sustainability is under-represented, this dimension becomes a focus for sustainability. With a paradigm where the economic and social dimensions become more important than the dimension of environment, sustainability is viewed as an anthropocentric idea. As appose, sustainability is viewed as an eco-centric paradigm as it majorly focuses on the dimension of environment compared to other dimensions.

In conclusion, this study suggests that it is unacceptable to weight the three dimensions of sustainability the same, as they are merited differently in other parts of the world. Instead it should be valued according to the needs of that particular case for sustainability. In the case of engineering education, it has been highlighted in several studies related to the principles of sustainability (see chapter 5) that the environmental and social dimensions are the main focus and have received a huge merit. This is due to the unequal sustainability dimensions in the existing curricula of engineering education (see chapter 5), where the social and environmental dimensions of sustainability are under-represented. Evolution of paradigm in interpreting sustainability in a particular context is necessary, as it serves for the equilibrium of the environmental, social and economic dimensions in the longer term. It is a state which, in this study, is defined as global sustainability.

The presented studies also demonstrate that sustainability is strongly related to the aspect of how long a system needs to be sustained. Some studies argued that the system is indefinite, where the system exists in a steady-state forever. In contrast, some other studies argued that the system is definite, with the existence of the system limited in time. In line with an argument to define the time-space of sustainability by Voinov and Farley (2007), this study argues that it is both an indefinite system and a definite system. In the system which is placed at the top of the hierarchy (a super system), sustainability of the system is indefinite while for systems at the lower hierarchy, sustainability of the systems are definite. Sustaining a system at lower level of hierarchy indefinitely could undermine the sustainability of super system and in fact, it could hinder the process of innovation and creation of better system. Therefore, according to Voinov and Farley (2007) a creative destruction is needed. “Sustainability is not about a lack of change. Rather, it is about appropriate rates of change for different levels in as system hierarchy”.

2.3 Sustainability concepts and principles

The views upon the concept of sustainability (the anthropocentric, eco-centric and equilibrium views) have bring understanding to this study that the three dimensions are fundamental to the concept of sustainability. Each view promotes different ultimate goal of sustainability. It is either solely on the human needs or absolute protection on the environment or the balance of the three dimensions. Each view determines the interactions between the three dimensions and the role of the dimensions to achieve global sustainability. To understand further the views upon sustainability and the three dimensions, this study will explore what are the concepts or principles underpinning these three dimensions of sustainability and explores the visual representations of the dimensions. Later on, this study will draw conclusions on the interactions of the three dimensions under the concept of sustainability.

The environmental dimension in sustainability

Environmental concern is always at the center of attention in most sustainability discourses. Robinson (2004) pointed out that, in the earlier 20th century the discourses on the environmental preservation were focused on the extraction of renewable resources, management of natural area and preservation of wilderness areas. Later, the issues concentrated on pollutions, population growth and non-renewable resource depletion (Boulding, 1966; Carson, 1962; Ehrlich, 1968; Hardin, 1968; Meadows et a., 1977; stated in the study of Robinson, 2004). For example, the concern for the environmental dimension in implementing the concept of sustainability can be traced to the use of "green indicators". It has been used by Qizilbash (2001) to study the issues related to poverty, well-being and environmental indices. The study has ranked 59 countries based on variables related to environmental concerns. The variables include water resources, forest and woodland, carbon dioxide emissions, commercial energy and fuel consumptions. In different cases, the study ranked 15 industrial countries based on the emission of sulphur dioxide, carbon dioxide and total commercial energy consumption.

The economic dimension in sustainability

From an economist point of view, the economic dimension that should be sustained usually is referred to in terms of capitals such as man-made capital, natural capital, human capital and social capital (Moldan et al. 2012). As stated by Barbier (1987) through the study of Munda (1997), sustainable development results in satisfaction "*of basic needs, enhancement of equity, increasing useful goods and services"* on economic system. This approach of the concept of sustainability also is followed by Goodland and Ledec (1987, stated in the study of Moldan et al. 2012) as the optimization of renewable resources without depreciation or elimination of the resources and without reducing its usefulness for future generations. The view also does not hinder the use of the non-renewable resources of current generation and accepting the use of the resources in the slow-rate of deterioration as it is adequate for the possibility of changes from non-renewable to renewable resources. In the same report by Moldan et al. (2012), they stated:

> *"Given the current financial and economic crisis, the economic aspects of development are under close scrutiny. The economic crisis shows that maintaining economic growth is an essential and universally accepted objective for the broad public. It should be noted that growth has been the most important policy goal across the world for the last five decades. It is the reason why it has been difficult to find a balance between sustainability and the economic growth of countries. Hopefully, the economic crisis could be an example of how to change the approach to economic growth and how to conceive of a new economy in terms of sustainable development." [pp. 5]*

The social dimension in sustainability

"The social dimension of sustainable development has received far less attention than the economic and ecological dimensions, both in policy circles and in academic writings" (Koning, 2002). Despite

of the predominance of the environment and economic dimensions in defining the concept of sustainable development, the social dimension has been incorporated fairly especially in the Agenda 21 in 1992 in Rio de Janeiro (Koning, 2002). Recently, the social dimension in sustainability has been defined into the context of urban social sustainability through a study by Dempsey et al. (2011). This study argues that:

> *"In order to access societal development, first of all the different relevant subsystems of the society must be identified. These encompass both subsystems that constitute society as those on which society depends: individual development, social system, government, infrastructure, economic system, and resources and environment. Each of these subsystems must be viable in order for the society to be viable".*

There is also another study that aims to identify the factors that contribute to social sustainability. The study of Dempsey et al., (2011) summarizes a series of literature related to social sustainability into the two factors of urban social sustainability, non-physical factors and physical factors (see Table 2.2). It addresses the connection between social sustainability and the context of urban in terms of equitable access and sustainability of community. Other than the factors to social sustainability proposed in Table 2.2, the dimension of social in sustainability also can be seen through the indicators of sustainable development and can be considered as an important part of the social dimension in sustainability. For instance, a study of Qizilbash (2001) used several indicators to rank countries in terms of its well-being. This study focused on variables such as life expectancy at birth, unemployment rate, suicide rate, adult illiteracy, underweight children under age 5, proportion of population with access to sanitation and consumption per capita. In addition, social dimension in sustainability also involves the issues of cultural diversity, institutional sustainability, social justice and participation (Barbier, 1987 stated in a study of Munda, 1997).

Table 2.2 Factors to urban social sustainability (Dempsey et al., 2011)

Non-physical factors	Predominantly physical factors
Education and training Social justice: inter- and intra-generational Participation and local democracy Health, quality of life and well-being Social inclusion Social capital Community Safety Mixed tenure Fair distribution of income Social order Social interaction Sense of community and belonging Employment Residential stability Active community organizations Cultural traditions	Urbanity Attractive public realm Local environmental quality and amenity Accessibility Sustainable urban design Neighborhood Walkable neighborhood: pedestrian friendly

Interactions among the three dimensions of sustainability

Before drawing a conclusion on the interactions between environmental, social and economic dimensions, this study has taken into account several views on the concept of sustainability, and varying perspectives on the underlying principles of sustainability. It is important to point out that the interactions depend on the definitions of sustainability which is either anthropocentric, eco-centric, or equilibrium views. In general, the interactions can be categorized into the following five rubrics: non-interactive, suppressive interaction, conditional interaction, integrative interaction and adaptive interaction. The interactions are built on the studies presented in this chapter.

The link between the environmental dimension and the social dimensions has been studied by Robinson (2004) through the analysis on the Brundtland report as a combination of radical and reformist. He stated that *"the radical aspect emerged from the explicit linkage made between environment and development issues. The report argued that the problems addressed by these two sets of issues are entwined to the point that ecological sustainability cannot be achieved if the problem of poverty is not successfully addressed around the world"*. *"The Brundtland report argued to integrate the vast and complex issues of environmental deterioration with the equally vast and complex issues of human development and poverty, and suggested that both had to be resolved simultaneously and in a mutually reinforcing way"*. He added the linkage is rather reformist with the anthropocentric view on the concept of sustainability presented in the Brundtland report.

Munda (1997) pointed out that the interaction between economic and environmental dimensions can be drawn by referring to the view of economy activity by the classical economist such as Malthus (1798), Ricardo (1817), Mill (1857) and Marx (1867). They (the classical economist) conceived process of economic system as an open system. It is also a system that is bounded by the environment. The study argued that, despite the idea of `zero growth´ for environmental preservation; the concept of sustainable development is appealing because the effort for environment conservation and economic development is not entirely conflicting to each other. The concept promotes the holistic approach of economic growth and environmental concerns.

According to Lèlè (1991), sustainable development can be achieved by preserving ecological and social sustainability and at the same time maintaining the traditional development objectives. Further, they explained that,

> *"In the mainstream interpretation of SD, ecological sustainability is a desired attribute of any pattern of human activities that is the goal of the development process. In other words, SD is understood as `a form of societal change that, in addition to traditional development objectives, has the objective or constraint of ecological sustainability´. Given an ever-changing world, the specific forms of and priorities among objectives, and the requirements for achieving sustainability, would evolve continuously. But sustainability – as it is understood at each stage – would remain a fundamental concern. Ecological sustainability is, of course, not independent of other (traditional) objectives of development. Tradeoffs may sometimes have to be made between the extent to and rate at which ecological*

sustainability is achieved vis-à-vis other objectives. In other cases, however, ecological sustainability and traditional development objectives (such as satisfaction of basic needs) could be mutually reinforcing. This interpretation of SD dominates the SD debate; …"[pp. 610]

The relationship between economic dimension and environmental dimension in the study of Lèlè (1991) is integrative. This is because both dimensions are equally important for sustainability. None of the dimensions is under-represented. However, in some cases where there are conflicts between two dimensions, tradeoffs have to be made. Depending on the aims of the cases, some components from one of the dimensions are compromising the other components from another dimension.

Harris (2000) suggested basic principles of sustainable development which could guide the development process.

i. *The original idea of development was based on a straight-line progression from traditional to modern mass-consumption society. Within this framework, a tension developed between the promotion of economic growth and the equitable provision of basic needs. Development as it has proceeded over the last half-century has remained inequitable, and has had growing negative environmental impacts.*
ii. *A concept of sustainable development must remedy social inequities and environmental damage, while maintaining a sound economic idea.*
iii. *The conservation of natural capital is essential for sustainable economic production and intergenerational equity. Market mechanisms do not operate effectively to conserve natural capital, but tend to deplete and degrade it.*
iv. *From an ecological perspective, both population and total resource demand must be limited in scale, and the integrity of ecosystems and diversity of species must be maintained.*
v. *Social equity, the fulfilment of basic health and educational needs, and participatory democracy are crucial elements of development, and are interrelated with environmental sustainability.*[pp. 18-19]

These principles promote a modification on the existing idea of development. It highlights social equity and environmental protection as the major concerns for sustainable development. Therefore, there are limitations for development growth and resource consumptions. In other words, the growth for development is permitted for the case that the basic needs are unfulfilled as long as the development not degrading the environmental and social aspects.

The concept of sustainability and the interactions amongst the three dimensions are frequently represented in the form of graphical illustrations. In general, the illustration includes the common dimensions of sustainability which are economic, environmental and social. In some cases, the three dimensions are elaborated to be more specific or focused to a narrow perspective. The interactions between the dimensions can be explained either through the link/connection of one illustration that represents one dimension to another illustration or through the connection of a dimension to the overall illustration. In the following discussions, the study presents several works from the past that envisioned the concept of sustainability and the interactions of the dimensions through graphical illustrations. Later at the end, this study proposes types of interaction that represent the relations between the three dimensions.

The interaction of the three key dimensions of sustainability has been many years envisioned through a Venn diagram, the illustration of three overlapping circles, introduced by the International Council for Local Environmental Initiatives (Connelly, 2007) depicted in Figure 2.2. The diagram demonstrates the relationship of three circles that represent the environmental, economic and society dimensions. SD concept is represented as the intersection area where the three circles overlap. The representation of sustainable development concept has been further developed and improvised from its original illustration over a decade and across continents.

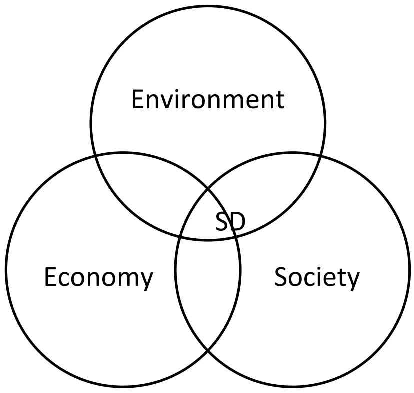

Figure 2.2 Illustration of SD concept proposed by ICLEI (1996)

The concept of sustainable development also has been represented (other than in a Venn diagram) using concentric circles, non-concentric circles, hexagon configuration, three-legged stool, a linear dimension (axis representation) and others (Lozano, 2008). The illustration of the concept not only demonstrates the interactions between the dimensions of sustainability but also the manifestation of the developer´s view towards the concept of sustainability. For instance, the following figure demonstrates integrational of the three dimensions of sustainability and views environment dimension as a universal dimension that contains and interact smaller dimensions within the cosmic (Mebratu, 1998).

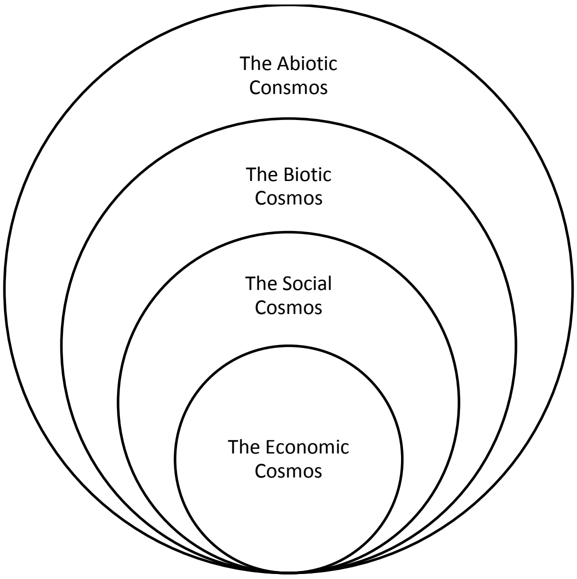

Figure 2.3 The Cosmic Interdependence (Mebratu, 1998)

Mebratu (1998) explained on the model of SD which has been developed based on the reductionist-holistic approach as:

i. *The human universe, in general, and the economic and social cosmos, in particular, never have been, and never will be, a separate system independent from the natural universe.*
ii. *The intersection area of the four cosmos is the area where we have millions of combinations of conflict and harmony serving as a seedbed for the process of coevolution of the natural and human universe.*
iii. *The vehicles of interaction within the interactive zone are millions of systems that do not belong exclusively to one cosmos but have a four-dimensional (three-dimensional, if we put the biotic and abiotic under the ecological dimension) systemic parameter.*
iv. *The environmental crisis recorded throughout human history is an outcome of the cumulative effect of deliberate, or otherwise, human neglect of one or more of the systemic parameters, resulting in millions of feedback deficient systems.*
v. *There is an abiotic region that is essentially free of interaction with the biotic, economic, and social cosmos; and by the same token there is a biotic region that is not yet in interaction with the human universe. However, neither of the regions be claimed to be free from the second-degree effect of the interactive region.* [pp. 514]

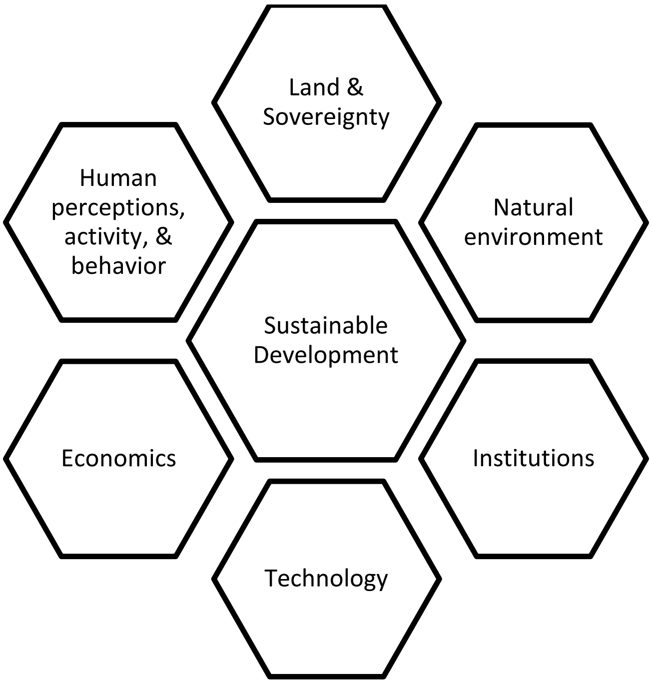

Figure 2.4 Menominee model of sustainable development (Van Lopik, 2013)

Van Lopik (2013) explained the Menominee model of sustainable development in his study, as a theoretical model that conceptualizes the process to maintain the balance and to reconcile the inherent tensions between six dimensions of sustainability. The dimensions stretch from the basic concept of sustainability to several elements, which are economics, human perception, activity, and behavior, land and sovereignty, natural environment, institutions, and technology. The dynamic relationship and organizations between the dimensions will generate the impact of each dimension on the other dimensions.

Approach	**Quasi-cornucopian**	**Social choice**	**New economics**	**Limits to growth**
Development	Current growth pattern	Marginal change	Substantial change	No growth
Environmental protection	Positive feedback possible	Trade-offs necessary	Negative feedback currently	Absolute limits to growth
Equity	Redistribution possible	Redistribution depends on growth	Redistribution a prerequisite for sustainability	Redistribution possible now
Key figures	Schimidheiny	Pearce	Ekins	Meadows, Daly
Sustainability spectrum	Weak---Strong			

Figure 2.5 Perspectives on sustainable development (Myerson and Rydin, 1996)

Several studies have shown the representations of the concept of sustainable development into a linear dimension (weak-strong dimension) e.g. Costanza et al. (1991), Myerson and Rydin (1996) and Hediger (1999). In general, strong sustainability is a principle that entirely focuses on preserving environment and ecology. Preservation of the environment in the context of strong sustainability is interpreted as sustaining some degree of natural capital indefinitely (Hediger, 1999). On the other end of the continuum, weak sustainability is interpreted as *"an integrative value principle, which requires that the total value of aggregate economy activity and environmental quality should be maintained intact over time"* (Hediger, 1999).

The same approach on representing the concept also concluded a study by Myerson and Rydin (1996) in the earlier 90s. This study outlined the representation of sustainable development by several authors e.g. Schimidheiny (1992), Pearce et al. (1993), Ekins (1986), Meadows et al. (1972) and Daly (1990) into three categories which are environmental protection, equity and development. The study viewed the approach of Quasi-cornucopian on sustainability proposed by Schimidheiny (1992) as a weak sustainability whereby the approach of limits to growth presented by Meadows et al. (1972) and Daly (1990) as a strong sustainability.

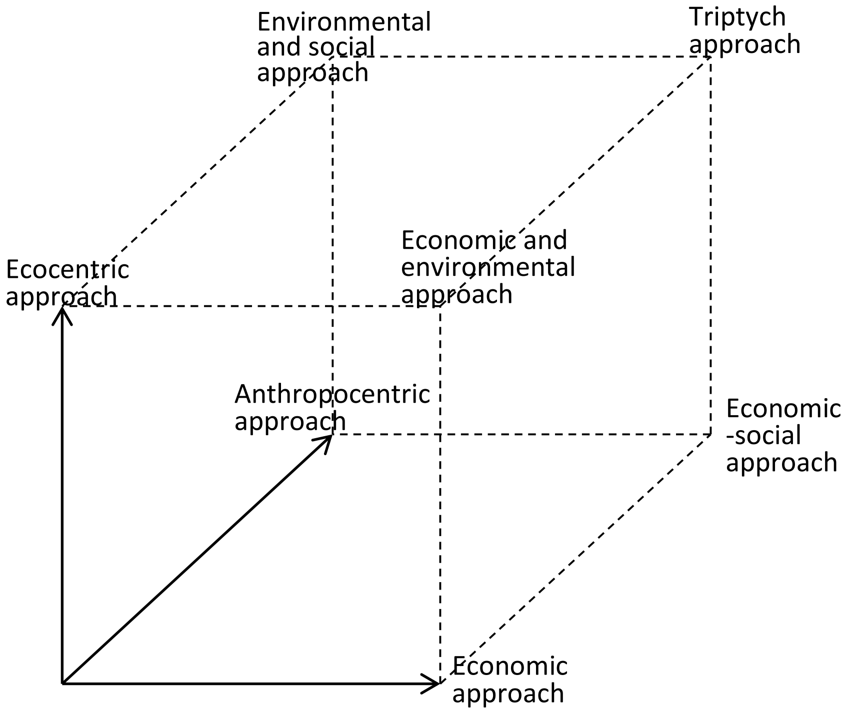

Figure 2.6 Interpretations of sustainable development (Lourdel et al., 2005)

Figure 2.6 demonstrates the varieties of interpretations towards the concept of sustainable development studied by Lourdel et al. (2005). The study developed a schematic representation to highlight the three dimensions which builds the original spheres representing the concept of sustainable development, triptych approach. The three approaches of eco-centric, anthropocentric and economic are considered as the extremist positions of the dimensions whereby environmental and social, economic and environmental, and economic-social approaches are intermediaries' positions. According to the study, an extremist approach e.g. economic on a system is not considered as an approach towards sustainable development. However, it is considered as a partial sustainable development if intermediaries' approach is taken on a system.

As the representations of the concept of sustainability are presented and discussed, the study could summarize the interaction of the element of sustainability into five forms. The interactions demonstrate how one element of sustainability is reacting towards other elements in the model, while all three elements are deemed essential for sustainable development and global sustainability. The interactions are i) Non-interactive, ii) Suppressive interaction, iii) Conditional interaction, iv) Integrative interaction and v) Adaptive interaction.

Non-interactive

The three dimensions of sustainability are considered to have no interaction if the concept of sustainability is solely defined to have either environmental or economic or social dimensions as the basic premises. For example, in the study of Mebratu (1998) which explained the two basic premises for the ecological conception of sustainability, the interactions of ecology to other dimensions do not exist. He explained:

> *"First, nature, left alone, is a self-organizing system that changes, responds, and evolves over time through a highly variable set of quasi-stable conditions. It is sustainable in the sense that it has no discernible goals or purpose. Hence, every ecosystem is self-controlled within larger scale constraints. Second, human beings seek to impose some constancy and dependability of supply of needed products through deterministic interventions". [pp. 511]*

Suppressive interaction

If the concept of sustainability is viewed as based on eco-centric or anthropocentric ideas, and it is the dominant view; the interaction of the dimensions of sustainability can be expressed as suppressive interactions. This is the case when one of the dimensions is a superior in a system compared to others and limiting or controlling the growth/development of other dimensions. The growth of that particular dimension(s) is either zero or negative if it is perceivably undermining the growth of the superior dimension. For instance if sustainability according to the eco-centric ideas is viewed as development of the economy, which in this case depends on the application of nonrenewable energy e.g. natural oil and gas, it is considered to reach the limit and therefore the growth of such economical activities must decrease or even disappear in order to preserve the energy.

Conditional interaction

This is an interaction that builds on a cause-effect relation. Once the criteria of one of the dimensions are fulfilled, it will affect the other dimensions in meeting their criteria for achieving sustainability. In other words, one of the three dimensions is a prerequisite to other dimensions and sustainability is hardly to realize as long as that particular dimension is unfulfilled. This interaction has been used to explain the issue of poverty within the concept of sustainability. It explains the interaction between the economic dimension and the social dimension. Poverty is a social issue involving equity in wealth distribution and it can be resolved by enhancing the economic growth, or by supporting the development of the economy.

Integrative interaction

Integrative interaction is an interaction that brings together two or three dimensions of sustainability (existing at lower level of a super system) into a system which is normally at a higher level in the super system hierarchy. These dimensions are equally important; none of the dimensions is superior to another. For instance, the integrative interaction between two dimensions can be seen in the concept of ecological economics which is frequent. It is a trans-disciplinary field that integrates and addresses ecosystems and economic systems in the broadest sense (Costanza et al., 1991). Similarly, Brundtland (1987) stated that the complex issues of environmental deterioration have to be addressed concurrently with the equally complex issues of human development and poverty.

Adaptive interaction

If the concept of sustainability is viewed as a concept focusing on the equilibrium of three dimensions of sustainability, the interaction between the dimensions is called adaptive interaction. This is due to the adaptability of the lower level system in hierarchy to react upon the undermine dimension(s) that threatens the sustainability of a super system. In other words, if one of the dimensions of sustainability in lower level is threatening the whole system, that particular dimension has to adapt i.e. adjusting the growth rate of the dimension, the need of a super system for sustainability. So it also explains that one of the dimensions can be a superior dimension in the past and can be an inferior in the future.

2.4 Sustainability in higher education

So far this study has shown various interpretations of the sustainability definition and the interactions between environmental, social and economic dimensions. Several studies e.g. UNESCO (1997) and Wright (2006) have highlighted the potential driver in achieving global sustainability and pointed out that learning institutions of higher education are one of the contributors. Therefore, the following parts of this chapter will explore further the connection between sustainability and higher education, and view the implementation of sustainability in higher education from the perspectives of campus operational, research and curricula.

For several decades, the role of higher institutions in providing graduates for professional area in all disciplines is without a doubt contributing to the economic growth and enhancing the quality of life. World has witnessed the changes of its landscapes and ecosystems due to the swift development and urbanization. It has been discussed in many cases that the human activities for development and urbanization endanger the ecosystem and contribute to unsustainable development. With these impacts, it is necessary for the learning institutions of higher education to respond to the need for sustainable development.

Sterling (2004) has viewed the interactions between education, society/economy and ecosphere as nesting systems. He stated that "it is possible to regard any educational system (a system of related components including policies, institutions, curricula, actors etc.) as a subsystem of wider society: it is organized by, financed by, and mandated by this society. It is shaped and oriented by the needs, policies, values and norms of the social context it serves". In these two ways of interactions between society and education, the role of education in society is not only defined by the learning institution itself but it has been defined by the society it serves. Furthermore, higher education is not isolated from the society rather it is built by the society and part of the system.

Sterling (2004) argued that in systemic view, "higher education largely `fails´ in terms of the latter two aspects of failure: the purposes or objectives of higher education largely fail to take into account sustainability, and undesirable side-effects…". In the context of the role of higher education for sustainability, the efforts towards sustainability and the implementations of the concept in higher education are supposedly through the institutions and society itself. With such failure, both higher education and society have to respond to the unsustainable approach on the operation of the institutions, the university researches and curricula. However, the responses as well as the practices are initially focusing on university/campus greening, ecological footprint of university and environmental management. Later in recent years, the responses focused on teaching and learning, outreach programs and partnerships (Wals and Blewitt, 2010). The following table shows the level of sustainability transitions representing the type of social and education responses.

Table 2.3 Social and education responses to sustainability (Sterling, 2004)

Sustainability transition	Response	State of sustainability	State of education
Very weak	No response	No change	No change
Weak	Accommodation ("Bolt-on")	Cosmetic reform	Education about sustainability
Strong	Reformation ("Build-in")	Serious greening	Education for sustainability
Very strong	Transformation (Redesign)	Wholly integrative	Sustainable education

Sterling explained further the differences of sustainability responses in education as presented in the following:

Table 2.4 Type of sustainability response in education setting (Sterling, 2004)

Accommodation	*"A bolt-on of sustainability ideas to existing system, which itself remains largely unchanged. This is adaptive response to the concerns of sustainability based on the values and modus operandi or instrumental rationality. There is minimal effect on the institution, and the values and behavior of teachers and students. This is often a content-oriented response, but it is characterized by incoherence and conflict between reflected educational values. For example, sustainability concepts such as biodiversity or carrying capacity may be added into some parts of the curriculum and some subjects, which in other respects carry messages*

	supporting unsustainability. The idea of sustainability and sustainable development is interpreted in ways which are consistent with the prevailing worldview. The descriptive term here is `education about sustainability´, or `learning about change´". [pp. 59]
Reformation	*"A building in of sustainability idea into existing systems. More coherent coverage of content, an attempt to teach values and skills perceived to be associated with sustainability, and attempts to `green´ the operation of the institution. There is some critical recognition of the dominant educational paradigm, its inadequacies and contradictions. The paradigm is modified and this is expressed in some changes in policy and practice. The descriptive terms here are `education for sustainability´, and `learning for change´.* [pp. 59]
Transformation	*"A re-design of sustainability principles, based on a realization of the need for paradigm change. This response emphasizes process and the quality of learning, which is seen as an essentially creative, reflexive and participative process. Knowing is seen as approximate, relational and often provisional, and learning is continual exploration through practice. The shift here is towards `learning as change´ which engages the whole person and the whole learning institution, whereby the meaning of sustainable living is continually explored and negotiated. There is a keen sense of emergence and ability to work with ambiguity and uncertainty. Space and time are valued, to allow creativity, imagination, and cooperative learning to flourish. Inter- and transdisciplinarity are common, there is an emphasis on real-life issues, and the boundaries between institution and community are fluid. In this dynamic state, the process of sustainable development and sustainable living is essentially one of the learning, while the context of learning is essentially that of sustainability. […] The descriptive term here is `education as sustainability´ or `sustainable education´.* [pp. 59-60]

The next part of this chapter will discuss the strategies taken by several universities in incorporating sustainability into their education system. In the discussion, the study will connect between universities strategies for the integration and the concept of sustainability responses i.e. accommodation, reformation and transformation responses which have been explained above.

Strategy of sustainability integration in higher education

Building on the reviews of previous perspectives and studies on the strategy of sustainability integration in higher education, Rusinko (2010) proposed an alternative the incorporation of sustainability concept into curricula. The study proposed four types of strategies which can be either incorporating sustainability into the existing structures or creating new structures, and either discipline-specific or cross-discipline. The proposal is presented in the matrix below.

		Sustainability in higher education delivery	
		Existing structures	New structures
Sustainability in higher education focus	Narrow (discipline-specific)	Type 1: Integrate into existing course(s) minor(s), major(s), or program(s)	Type 2: Create new, discipline-specific sustainability course(s), minor(s), major(s) or program(s)
	Broad (cross-discipline)	Type 3: Integrate into common core requirements	Type 4: Create new, cross-disciplinary sustainability course(s), minor(s), major(s), or program(s)

Figure 2.7 Matrix to integrate sustainability in higher education

Rusinko (2010) views these four types of strategy as opportunities to materialize even with limited resources and man power (type 1), to standardize an independent identity (type 2), to cross-discipline and expose to large number students (type 3) and to create independent identity across disciplines (type 4). Beside these advantages, the study shows that the implication of these strategies is not only in terms of its capability to materialize, or number of students and disciplines, but it could also affect the overall knowledge of the courses or contents, influence the approach of teachers in choosing learning activities and eventually enable sustainability thinking for both teachers and students. If the teacher decides to integrate sustainability into an existing course, he/she has to understand that embedding concept of sustainability could change the knowledge of the course, especially for a course that is fundamentally anthropocentric or techno-centric or even eco-centric. Not only that, the teacher also has to consider redesigning his/her teaching strategies or learning activities, since the integration of sustainability concept changing course learning objectives includes learning activities and assessment techniques. Hence, the original intention of sustainability integration in higher education is achieved.

In the study of Redman and Wiek (2013), they have reported the effort of Arizona State University in integrating sustainability in higher education by the establishment of a school of sustainability. The study outlined six cornerstones that could describe the school. First, the school focuses on the urgent and important issues that are related to sustainability which, in their perspective, in order to address these issues “sustainability requires a new paradigm, and the educational system must be transformed to accommodate it”. Second, the school employed epistemological pluralism which could provide a better understanding by integrating several perspectives from several disciplines. It is believed, a disciplinary approach in addressing issues related to sustainability only provides a single sided perspective, which is incomplete and unable to accommodate the demand of sustainability issues. Therefore, pluralism in research epistemology could fulfill the demand. Third, the school provides a platform for practitioners, scientist and stakeholders to work together hand-in-hand in conducting studies that contribute to the generations of knowledge. Fourth, importance is attached to have real-world learning experiences in teaching and learning activities in order to address real-world problems. This approach in an educational setting could result in gain in professional skills amongst students which could not happen in a traditional learning environment.

Fifth, emphasize the concern of the future for sustainability. This cornerstone permits transformation or rather a drastic change where sustainability is a top priority. The study explains "implicit in an emphasis on futures is recognizing the necessity of working with input from stakeholders, and an ability to incorporate diverse values attributed to alternate outcomes by different participants". As the final cornerstone, they provided additional competencies beyond the expected learning outcomes from most disciplines.

From the experience of Arizona State University in integrating sustainability, this study learnt that the establishment of school of sustainability has proven the potential to have a drastic change either in teaching and learning activities or research activities. It is important that the school emphasizes an interdisciplinary approach in teaching and learning activities as well as different forms of participations of professionals to build understanding of sustainability knowledge. However, the establishment of new institution without direct integration into the existing educational system could create a parallel educational system. In a system where a \`sustainable´ education system exists concurrently with an \`unsustainable´ education system, the impacts of a sustainable education system to the entire university is minimal. It is important to address that the integration of sustainability has to institutionalize, as Sterling (2004) referred, as a wholly integration (a transformation towards sustainability). The establishment of a new institution that employs the concept of sustainability could be an opportunity to move for institutionalization of sustainability and as the change agents for the university or higher education.

An example of institutionalization of sustainability in higher education can be found in the experience of Griffith University Australia, a study reported by Heck (2005). By reviewing the implementation of sustainability in the context of teaching, research, management (operational practices), community service and university leadership, the study highlighted several actions taken and recommendations to improve the institutionalization of sustainability in the respective university. The response towards sustainability for this case is closely as mentioned by Wals and Blewitt (2010) as a very strong sustainability transition. The university has integrated the portfolio related to coordination of university´s sustainability initiatives, networks among stakeholders and effective communication which includes internal and external communications into the top executives e.g. Vice-Chancellor and Deputy Vice-Chancellor of the university.

Unlike other universities, which mostly established a new committee of sustainability (either an academic committee or a research committee) separated from the existing university committees, Griffith University in Australia redesigned the terms of reference (ToR) of two major standing committees of the universities to include and integrate sustainability. In addition to the effort of the integrations, the study reported that the university has redesigned the policies and approach for practices towards sustainability, incorporated sustainability in university´s strategic plan and operational plans, built an association with University Leaders for a Sustainable Future and led the development of an Australian Network of Sustainable Universities and Asia-Pacific Network.

Lozano (2006) discussed in his study on how the transformation of a university towards sustainability from individual approach to institutional approach is tackled. Pointing out the importance of an individual approach in the effort of a university towards a sustainable school, the study proposed several solutions to overcome barriers (which will emerge in every level) and strategies for individual as well as an organization to institutionalize sustainability in university level. Lozano (2006) views the institutionalization of sustainability as a process starting from the individual initiative on sustainability to incorporation (as a change agent). As the number of the individuals increases, the understanding, knowledge and skills of these individuals will lead to the incorporation of sustainability at a higher level (organization level) e.g. an educational program, a discipline. Consequently, the emerging group(s) of individuals eventually moves the transformation from organization level into institution level. As the study argues, the institutionalization usually takes significantly a long time to implement as it demands cooperation of many individuals and organizations especially the change agents and university´s stakeholders. The study of Lozano (2006) suggests that in the process incorporation of sustainability, the following approaches could possibly be useful.

i) *Make SD explicit in the universities´ academic policies, institutional mission, strategy and planning.*

ii) *Appoint an SD coordinator, who acts as a champion, to coordinate the SD institutionalization process. A multi stakeholders committee should be established to help the SD champion to plan and coordinate the implementation process.*

iii) *Involve stakeholders in all the phases of the process of incorporation and ensuring continuity of the SD program, SD demands stakeholder participation; it is also highly advised that all the disciplines contribute their knowledge.*

iv) *Reduce the fear of change to incorporate SD by providing the necessary information to everybody that addresses the rational of certain individuals, using the empirical-rational strategy.*

v) *Incorporate SD into all five academic dimensions (curricula, research, campus operations, community outreach, assessment and reporting).*

vi) *Communicate regularly, the goals, objectives, processes, progress and future plans of the SD efforts to all stakeholders within and outside of the academic context.*

vii) *Develop and utilize specific strategies to overcome the barriers to change, at all levels. Specifically the level of "resistance involving deeper issues" and "deeply embedded resistance", since "resistance to the idea itself" level can be overcome with information. A powerful and useful strategy to achieve this is the normative-educative, where the different individuals are involved in SD projects, thus reducing their resistance to change.*

viii) *Achieving the multiplier effect can reduce the time of SD adoption; this can be achieved by identifying and encouraging some of the individuals involved in small projects to share their experience and knowledge. The multiplier effect can also be achieved by educating educators to educate other educators and thus obtain a multiplier effect.*

ix) *Incorporate SD into the everyday life of all on campus; it should not be seen as an abstract concept that does not relate to the day-to-day work.*

x) *Understand and meet individual needs; if the individuals do not internalize SD the institution will never be sustainable.* [pp. 794-795]

In the context of the incorporation of sustainability into university courses and curricula, the differences in terms of its strategies are varied to one and another. The strategies very much reflected the aims or goals of that particular organization or institution set for the incorporation. If the institution was aiming for a complete transformation of their curricula towards sustainability, affecting all existing programs and courses, it demands full cooperation from all teachers and staff. The strategies that have been planned for the transformation are more complex, demanding a high degree of participation and time consuming compared to an institution that has decided to incorporate sustainability by only introducing a new course and embedded into the existing curriculum.

As an example of incorporation of sustainability, Lidgren, Rodhe and Huisingh (2005) reported a systemic approach employed by Lund University, Sweden to bring sustainability in their courses and curricula. First, the university systematically identified barriers that hinder the incorporation of sustainability and proposed solutions or ways that could eliminate the barriers. The report stated that, new indicators that could be used to assess student´s competencies contribute to the need for sustainability development and implementation. It is believed that, by introducing sustainability aspects as criteria of student's assessments it will influence student´s behavior. The report also suggests both teachers and students of Lund University participating in multidisciplinary courses related to sustainability. This approach could widen the window of opportunities for teachers and students from various disciplines and area of studies to exchange their perspectives and understanding on the issues of sustainability. These knowledge exchanges could strengthen the understanding of teachers as well as improve sustainability related courses offered by the university. Another solution proposed to overcome the barriers is by utilizing discourses on issues of sustainability with university stakeholders. The participation of internal and external stakeholders in discourses is important either for redesigning the visions and goals of the university or for implementing plans to achieve sustainability.

In Malaysia, the efforts of four research universities (Universiti Malaya, Universiti Sains Malaysia, Universiti Kebangsaan Malaysian and Universiti Putra Malaysia) in incorporating sustainability in higher education included the aspect of campus operations, teaching and learning activities, researches, outreach programs and services (Saadatin et al., 2012). The universities, in general have shown great commitment to enhance the quality of education, public participations and knowledge generations which highly emphasize the social dimension of sustainability in their university policies and plans. However, these efforts over-emphasized the aspect of the social dimension and has underdeveloped the importance of environmental aspect in university leaderships except for Universiti Sains Malaysia that approaches the concept of sustainability by incorporating the three dimensions explicitly in the university´s visions and missions (Saadatin et al., 2009).

Even though the economic and environmental dimensions are underestimated in the policy level of universities, Saadatin et al. (2009) reported that these dimensions are incorporated in the engineering programs and courses. In fact, most of the programs and courses focus on issues related to the environmental dimension, such as Bachelor of Environmental Engineering (program level), Bachelor of Civil and Environmental Engineering (program level), and Integrated approaches to sustainable development practices (course level). The report is also an evidence of the limitations of education reform in the four universities in developing engineering education for sustainable development. All presented cases demonstrate a disciplinary approach in implementing plans of the incorporation. The incorporation is mostly in civil and environmental engineering and literally non-existent in other engineering fields e.g. mechanical engineering and electrical engineering. The "re-formation" of engineering education towards sustainability of the universities is breaking down interdisciplinary or trans-disciplinary approaches in redesigning existing courses, as it usually is highly content oriented and ignoring reformation on teaching and learning activities.

Other studies, suggest a few more concerns that need to be addressed. For example, in initiating the integrations of sustainability in higher education Fieselman and Lindquist (2013) recommend:

i. *Begin curricula work by engaging current or latent personal and/or professional sustainability interests of faculty.*
ii. *Utilize existing campus expertise wherever possible, inviting outside expertise when appropriate or to re-energize faculty when necessary.*
iii. *Actively listen to students´ professional interests and create academic opportunities in these areas.*
iv. *Initiate and implement changes quickly, as students are eager for sustainability learning opportunities.*
v. *Define and redefine "sustainability" as the campus works together, ensuring students, faculty, and administration are working from a common place.*
vi. *Employ AASHE´s resource center, events and web conversations for support and guidance.*

Another example is presented in one of the results of the transformation at higher education reported in a study by Van Lopik (2013). The university strategized their effort to integrate sustainability across the curriculum by employing several factors. The strategies taken are as follows:

i. *Collaboration between institutions with relevant stakeholders.*
ii. *Commitment of top management/leaders to highlight sustainability*
iii. *Recognition of sustainability in research funding*
iv. *Integration of sustainability in institution policy*
v. *Implementation of sustainability in the classroom through problem based learning*
vi. *Integration of sustainability into learning objectives*
vii. *Discussion on sustainability with a broader audience*

So far in this chapter, several studies are presented on the strategies of higher education to incorporate sustainability and the studies in the perspectives of sustainability responses highlighted by Sterling (2004) were discussed. The next part will present some examples of the efforts of sustainability incorporation in engineering curricula from studies by García- Serna et al. (2007), Hesketh et al. (2004) and Kumar et al. (2005) as a brief overview on the practices. An in-depth study on the incorporation of sustainability in engineering curricula will be presented and discussed in chapter five (Phase One: Exploring real world practices) and chapter six (Phase Two: Highlighting positive practices).

Incorporation of sustainability in engineering curricula

"Education is crucial to expand understanding, skills, and motivation to shift society towards sustainable development. The educational system produces professionals who ultimately develop products and processes and who run and manage production systems. For the case of engineering, education is an essential premise to promote concepts such as sustainability, green engineering and pollution prevention, especially at universities and other institutions of higher education which are closer to professionals. Sustainability-oriented teaching and research is not only important in natural and technological sciences, but also in economics and business administration" (García-Serna et al., 2007). [pp 27]

García- Serna et al. (2007) exemplified the incorporation of sustainability in engineering education in the form which has been referred to in this study as a bolt-on approach or a cosmetic reform on engineering education. The study highlighted the incorporation by simply inserting topics of sustainability that is conceptually suitable or seems compatible to the existing epistemology of the course. The insertion can be either highly related to the core contents of engineering or connecting the understanding of students by interrelating the concept of sustainability with their daily-life i.e. students have to conduct analysis on their water or energy consumption in a day. The study also reported the common practice amongst engineering schools/institutions to introduce sustainability by conducting/offering elective courses that are specifically designed for this purpose. This type of courses are usually offered to final year of undergraduate students or to postgraduate students, in which from the perspective of its implication to engineering education; this approach is generally unable to shift the world view and understanding of the role of engineers towards sustainability. The study argued that "by placing green engineering courses at the end of their university formation period (for example as a master or PhD formation), it can leave the impression that environmental aspects should be considered when the design is already finished". Therefore the "green engineering should be conducted at all levels of engineering practice and design".

The study also suggested several steps for the incorporation as below (García- Serna et al., 2007):

i) *Identification of the current state-of-the-art, capabilities and future necessities.*
ii) *Analysis of core and special courses, topics, and activities.*
iii) *Finding core and special training opportunities.*
iv) *Finding cross-linking training opportunities.*
v) *Definition of the Agenda of implementation within the structure i.e. undergraduate, master and doctorate.*

vi) Pilot project implementation and testing.
vii) Modifications to the plan.
viii) Final approval and implementation.
ix) Monitoring of the plan.

Driven by the recognition of the US Engineering Accreditation Commission´s Accreditation Board for Engineering and Technology (ABET) and the adaptation of a "green approach" in major chemical companies, the incorporation of sustainability in engineering curricula (in this case chemical engineering curricula) is conceived essential. In Hesketh et al. (2004), the incorporation of sustainability in chemical engineering curricula is called `green engineering curriculum initiatives´; and they have introduced the concept of sustainability by creating stand-alone courses and embedding the concept into the existing core engineering courses. Initially, most universities in the United States of America create environmental courses including air and water pollution control, and pollution prevention, as a stand-alone course and targeted for graduate students. Frequently the environmental-related courses are offered as elective courses which are not compulsory for every graduate student who had signed up for the courses but the courses are open to all graduate students regardless of their field of studies and disciplines. Due to the increase awareness of the importance of environmental issues, the environmental-related courses have been incorporated in undergraduate engineering curricula i.e. in Rowan University, specific courses have been redesigned for this purposes, introduced as Freshman Engineering Clinic and Sophomore Engineering Clinic. The study also reported that Rowan University has embedded the concept of sustainability into the existing engineering courses such as Material and Energy Balances, Separation Processes and Plant Design.

Concerning the establishment of sustainability requirements in the ABET standards, Kumar et al. (2005) has proposed a method to incorporate sustainability in mechanical engineering curricula. So that, sustainability could be embedded across academic years of undergraduate studies and could be embedded in more advanced mechanical engineering courses. The study highlighted the method of the incorporation of sustainability in Mechanical Engineering by infusing sustainability modules into `general education´ courses, `technical elective´ courses and advanced Mechanical Engineering courses. The study also highlighted the importance of helping students to understand the concept of sustainability by participation of students from various field of studies and disciplines. This interdisciplinary and multi-disciplinary approach can be materialized by intertwining courses in humanities, social sciences and engineering through a single topic or a project. Other than the aspect of interdisciplinary, the study had also taken into accounts the importance of enhancing problem solving skills amongst mechanical engineering students. It is believed that the students should be given hands-on experiences that are complex and simulate real-world situations so that they can understand the connections between society, environment and engineering practices, as well as the connections between theories and practices.

2.5 Curriculum models

In this part of literature review, the study highlights several models of curriculum design which have been practiced by most of universities and several models that have been proposed for educational improvement in higher education. The study will discuss a traditional curriculum development model reported by Cowan et al. (2004), a constructive alignment model (Biggs, 2003), a logical model (Cowan et al., 2004), a process model (Knight, 2010), and a problem based learning (Kolmos, de Graaff and Du, 2009). Later in this part, this study put in perspectives the context of curriculum design on the efforts to incorporate sustainability in higher education.

A traditional curriculum development model

For many years, curriculum developers have been committed to design curricula for higher education guided by a linear process of design depicted in Figure 2.8 below. In a chronology sequence, the process of curriculum design constantly highlights those components in a linear process (includes several feedbacks) which have been reported in the study of Cowan et al. (2004). The process starts by determining aims and outcomes, followed by choosing suitable teaching methods. Next, the teachers will plan on their teaching and delivery approaches, assessing students, obtaining feedbacks from students, and evaluating the course. Each of these processes is expected to produce some sort of feedbacks (e.g. reviews and reports from evaluation process) in order to improve the aims and the teaching methods.

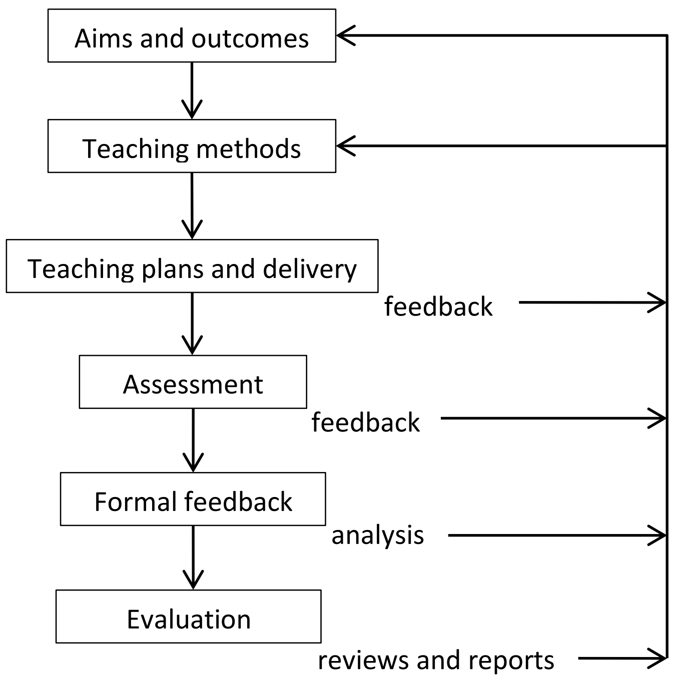

Figure 2.8 A traditional curriculum development model

Cowan et al. (2004) stated that there are problems with the model because:

i) It assumes that aims, objectives and outcomes are only considered, and reviewed, once per cycle or iteration.
ii) It concentrates on teaching rather than learning.
iii) It presents learning as a consequence of teaching, rather than teaching as one, but not the only, input to learning.
iv) It obscures the relationships between the elements of process.
v) It neglects the possibility of utilizing external inputs to this process.

A constructive alignment model

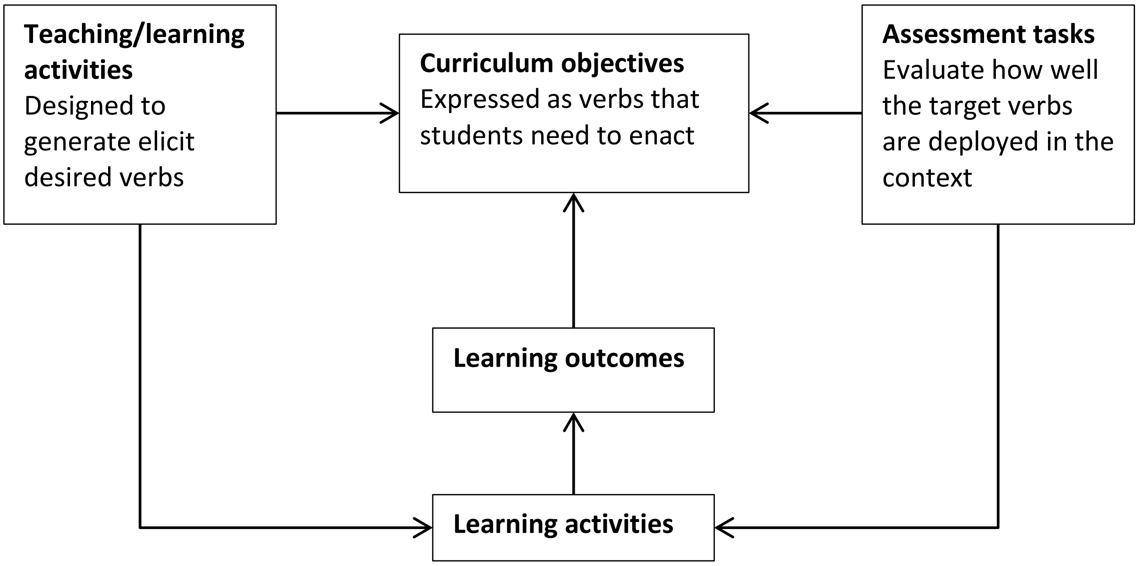

Figure 2.9 A constructive alignment model (Biggs, 2003)

The constructive alignment model highlights the importance of the alignment of curriculum components which includes curriculum objectives, teaching and learning activities, assessment tasks and learning outcomes. It is a model that has been proposed by Biggs (2003) aiming to overcome the drawback of the traditional transmission theories that ignore alignment of these components. Figure 2.9 depicts the interrelations of each of curriculum components towards curriculum objectives. In constructive alignment model, the objectives of curriculum are the most important component of the curriculum design and benchmarking of the student´s learning outcomes. In fact, learning objectives are the reference for curriculum developer to plan teaching and learning activities (which aims to achieve curriculum objectives) and to design assessment tasks as well as assessment tools. According to Biggs (2003),

> *"constructive alignment is a design for teaching calculated to encourage deep engagement. In constructing aligned teaching, it is first necessary to specify the desired level or levels of understanding of the content in question. Stipulating the appropriate verbs of understanding helps to do this. These verbs then become the target activities that students*

need to perform, and therefore for teaching methods to encourage, and for the assessment tasks to address, in order to judge if or to what extent the students have been successful in meeting the objectives. This combination of constructive theory and aligned instruction is the model of constructive alignment."[Pp. 32]

A logical model

This model, based on a study by Cowan et al. (2004) is more advanced than the traditional curriculum model and inspired by a constructive alignment model. By positioning "Aims" at the central part of the model (depicted in Figure 2.10), it is expected that the aims of a curricula (can be a course) are influencing four other components of the model except "decisions" component, which are assessment, learning, teaching and evaluation components. The model proposes that, first the assessment plan has to be designed before planning the teaching and learning activities of the curricula. The model also highlights the importance of aligning the four components of curricula (assessment, learning, teaching and evaluation) with the aims (which consider the decisions for change as an input i.e. results from analyzing the outcomes of the evaluation process), simultaneously. The process of curriculum design (enclosed in a circle) is expected to get influenced by the external factors such as university policies or accreditation requirements, which often encourage educational improvement.

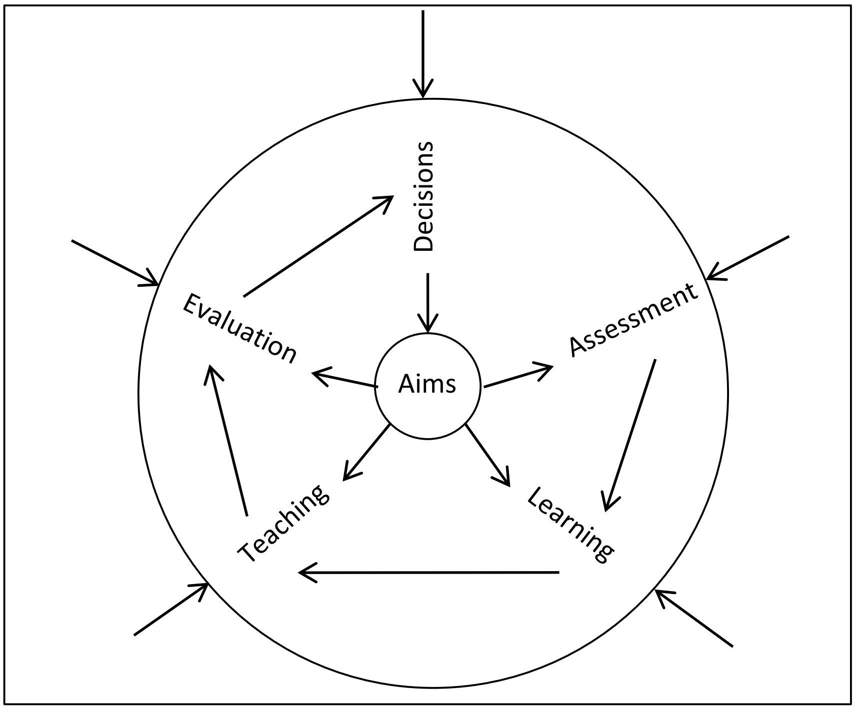

Figure 2.10 A logical model (Cowan et al., 2004)

A process model

Unlike the three curriculum models presented above, a process model is a curriculum model that emphasizes on teaching and learning process which aims for good learning (Knight, 2010). In designing a good learning experience, the model proposes the designer to concentrate on envisioning teaching and learning activities (including assessment) which can be associated with complex learning. As Knight (2010) suggested in his work, some key teaching and learning encounters are associated to a complex learning as follows:

Teaching encounter;

i) *Alert them to the `rules of the game´- make them aware of what is valued and how it may produce, both in general and in each case.*
ii) *Use the requisite variety of media (face-to-face, audio visual, on-line conferencing, asynchronous OCT).*
iii) *Use the requisite variety of methods (presentations, action learning sets, work experience, seminars, proctoring, tutorials, computer-assisted instruction, and independent study projects).*
iv) *Be in a variety of styles (coaching, instructing, facilitating, and clarifying).*
v) *Meet the standards indicators of good teaching, namely interest, clarity, enthusiasm.*
vi) *Be structured across the program as a whole so that students get progressively less help and guidance from teachers as they encounters more complex situations, concepts, arrangements, etc.*
vii) *Be summarized in a program-wide teaching summary.* [pp. 375]

Learning activities;

i) *There should be opportunities for depth study*
ii) *Curriculum should not be so crowded that `surface´ learning is encouraged at the expense of understanding.*
iii) *ICT should be treated as a normal learning tool.*
iv) *They should expect to work collaboratively, whether learning tasks require it or not.*
v) *Time for strategic thinking, reflection, planning and portfolio-making should be written into the program; students should know that; and they should know that they are expected to engage with these learning activities involving peers, friends and tutors.*
vi) *There should be plentiful feedback that is intended to help future performance (rather than identifying informational lapses), especially by encouraging self-theories that value effort and mindfulness.*
vii) *This should be summarized in a program-wide learning summary.* [pp. 375]

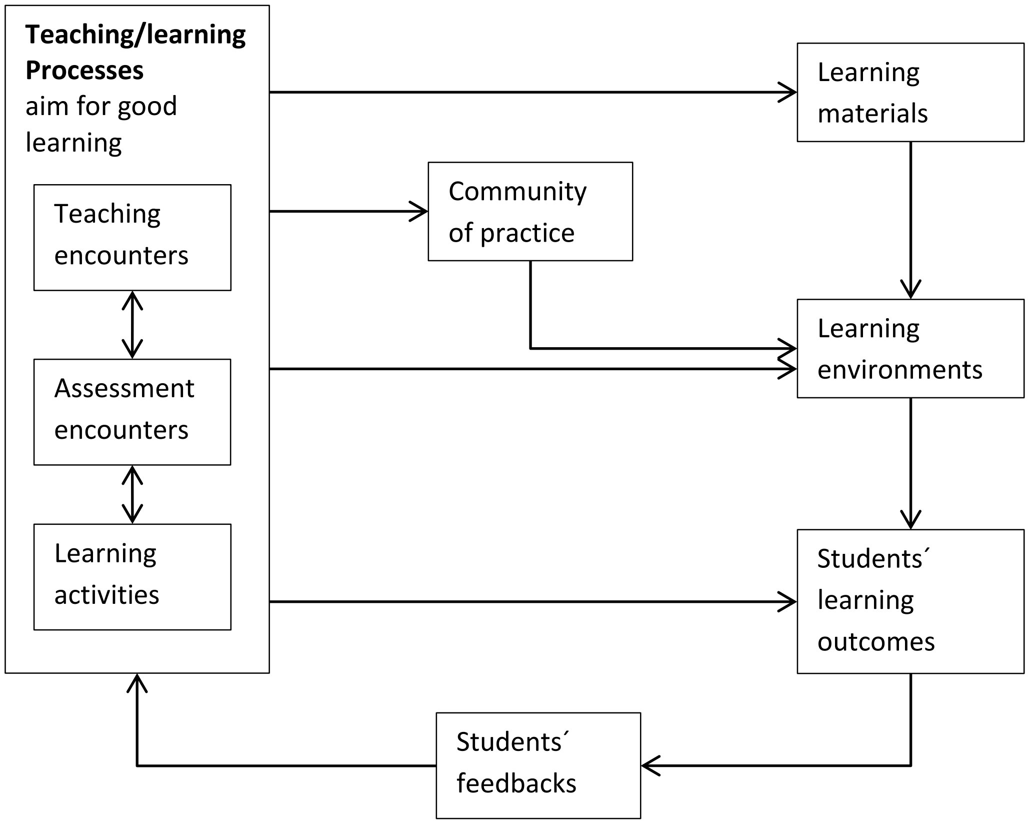

Figure 2.11 A process model

Figure 2.11 depicts a process model, a model for curriculum design, illustrated from a study of Knight (2010). The figure shows that the teaching and learning activities of the curricula are the key to the selection of course materials, providing engagement to the community of practice, creating learning environments and eventually contribute to students' learning outcomes. Similarly, this model also concerns on the concept of alignment between components of curriculum design which has been mentioned in a constructive alignment model and a logical model.

In this case, the alignment (or coherent) is applied within the process of designing good learning activities which includes the components of teaching encounters, assessment encounters and learning activities. In order to improve teaching and learning activities, this model sees students´ feedbacks on the aspect of the learning outcomes as a method. The study argued that, to achieve what the study refers as a successful complex learning (which has been associated in the study as a good learning); it implies that *"curriculum should carry another set of messages, largely in the form of feedback to students in assessment conversations about their achievements and how to improve upon them"*.

A problem based learning model

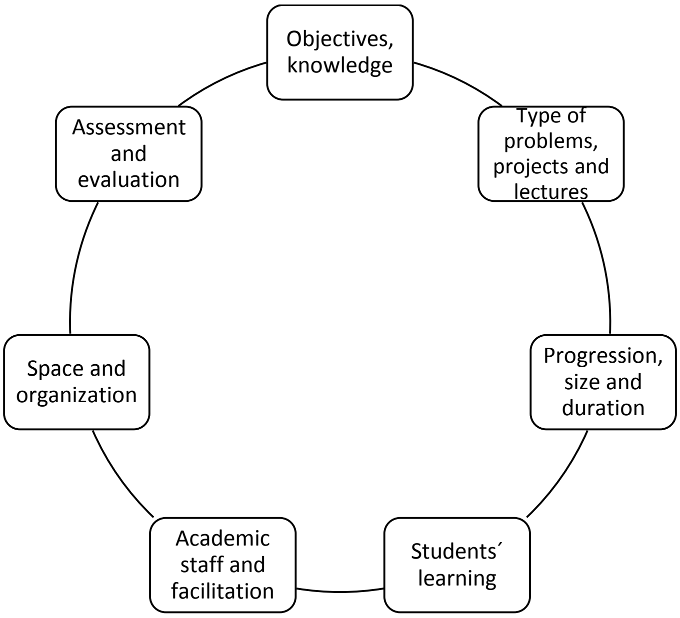

Figure 2.12 Problem and project based alignment model (Kolmos, de Graaff and Du, 2009)

Inspired by Savin-Baden´s Problem based learning (PBL) model; Kolmos, de Graaff and Du (2009) developed a model that collectively aligns the important components in designing curricula in a problem and project based learning environment (see Figure 2.12). The curriculum is designed based on a common problem that students are collaboratively working on, and the nature of the problem influences the process to develop and manage projects and to organize teams. There are seven components that have been proposed in this model, it comprises i) objective and knowledge, ii) types of problems and projects, iii) progression and size, iv) students´ learning, v) academic staff and facilitation, vi) space and organization, and vii) assessment and evaluation.

In context of PBL implementation, the study represents PBL practices into a spectrum of PBL components (the seven components presented earlier). Figure 2.13 depicts the spectrum between two extreme PBL practices, which is from i) a discipline and teacher-controlled approach to the another extreme end which is ii) an innovative and learner-centered approach. The spectrum not only explains the variety of PBL implementations but it also characterizes the practices. A discipline and teacher-controlled PBL curriculum frequently aims to address a particular knowledge of the discipline and the provided problems are typically narrow, well-defined and determined solely by the lectures. Students are collaborated for their individual learning and acquiring knowledge. On the other hand, an innovative and learner-centered PBL curriculum promotes interdisciplinary learning by providing ill-defined problems or open-type of projects that encourage innovations. Students are collaborated potentially for innovation process and participated in knowledge construction. It is learnt from the study that, the spectrum is potentially a useful tool for curriculum designers to align the seven components in designing a PBL based curriculum.

	Discipline and teacher-controlled approach	Innovative and learner-centred approach
Objectives and knowledge	*Traditional discipline objectives* *Disciplinary knowledge*	*PBL and methodological objectives* *Interdisciplinary knowledge*
Types of problems and projects	*Narrow* *Well-defined problems* *Disciplined projects* *Study projects* *Lectures determine the project*	*Open* *Ill-defined problems* *Problem projects* *Innovation projects* *Lectures to support the project*
Progression, size and duration	*No visible progression* *Minor part of curriculum*	*Visible and clear progression* *Major part of course/curriculum*
Students´ learning	*No supporting courses* *Acquisition of knowledge* *Collaboration for individual learning*	*Supporting courses* *Construction of knowledge* *Collaboration for innovation*
Academic staff and facilitation	*No training* *Teacher-controlled supervision*	*Training courses* *Facilitator/process guide*
Space and organization	*Administration for lecture based curriculum* *Traditional library structure* *Lecture rooms*	*Administration supports PBL curriculum* *Library to support PBL* *Physical space to facilitate teamwork*
Assessment and evaluation	*Individual assessment* *Summative evaluation*	*Group assessment* *Formative evaluation*

Figure 2.13 PBL spectrums by its components (Kolmos, de Graaff and Du, 2009)

Curriculum design for the incorporation of sustainability in higher education

As mentioned in Chapter 1 (Introduction), the objectives of this research are i) to develop a design framework to incorporate sustainability in engineering curricula and ii) to contribute to sustainability integration in Malaysian higher education . In chapter 5 to 9 a series of studies will be presented with development activities and analysis aiming to achieve these objectives. Based on the discussions in this chapter, the following aspects are believed to be important to highlight in the process of incorporating sustainability into the existing curriculum. These aspects emerge from the above discussions on the definitions of sustainability, concepts of sustainability, sustainability in higher education and curriculum models.

i) To determine principles of sustainability for the incorporation

In the earliest part of this chapter, the definitions of sustainability have been discussed systematically. It was found that sustainability has been defined from three different perspectives which are anthropocentric, eco-centric and equilibrium views. Sustainability also has been defined in terms of time-space (how long a system should be sustained?), either as a definite system or an indefinite system. Several studies have shown that the concept of sustainability is built on three main dimensions: environmental dimension, social dimension and economic dimension. The interactions amongst these three dimensions however, differ from one concept to another. The study has concluded that the interaction of the three dimensions can be classified as non-interactive, suppressive interaction, conditional interaction, integrative interaction and adaptive interaction. Learning from the variety of sustainability definitions and concepts is fundamental for a curriculum designer to determine the definition and concept that can be translated as principles of sustainability. By determining the principles of sustainability before redesigning a curriculum, the contradictions between the definitions of sustainability and the concepts of sustainability can be minimized and compromised.

Standing on a single definition and concept of sustainability, the following works and discussions in this study are fundamentally referred to an equilibrium view of sustainability. It is a view believing that sustainability can be achieved by equally valuing the dimension of environmental, social and economic. This study fundamentally accepts that the global sustainability is expected to last forever and on the other hand regional/local sustainability is limited in time. Each dimension interacts adaptively from one to another, which explains the adaptability in terms of its priority. Owing to these beliefs, this study outlines several principles for the effort to incorporate sustainability in engineering curricula. The principles are:

1. The incorporation must contribute to the global sustainability, which is aiming for an equilibrium state in indefinite time.
2. The incorporation must focus on the under-represented dimension(s) without undermining other dimensions.
3. The focus of the incorporation must adapt the current state of global sustainability.
4. Eliminate or reduce dimension(s) that threaten the global sustainability.

ii) Plan strategies for the incorporation

Without a doubt there is a necessity for a curriculum designer to plan ahead the strategies to incorporate sustainability in higher education. Several studies in this chapter reported universities´ strategies to incorporate sustainability into their curricula. Furthermore, this study has argued some strategies into the aspects of educational responses towards sustainability introduced by Sterling (2004). This study demonstrated that several questions have to be answered during the process of planning the strategies:

1. To what extent the incorporation of sustainability will take place in the educational system?

   Each level in educational system gives impacts on the institution (e.g. policies and operations), teaching and learning (e.g. programs and courses), researches, and community (e.g. outreach programs) differently. Therefore curriculum designers could be concern on the three kinds of educational responses on sustainability from Sterling (2004), either an accommodation response, reformation response or transformation response.

2. What are the principles of sustainability (including the definition and concept of sustainability) that will be incorporated in the educational system?
   This is where curriculum designer takes into consideration the existing educational principles and makes changes on the existing educational system to be aligned to the principles of sustainability.

3. What are the goals and aims?
   This is a question to refine the existing educational goals or aims including the programs´ learning outcomes.

The incorporation of sustainability in this study concentrates on the engineering programs and curricula. It aims to provide full flexibility for curriculum designers to either accommodate or reform or transform the existing engineering curriculum for sustainability. This flexibility permits a curriculum designer who has limited authority to make changes in the existing curricula to incorporate sustainability. It also provides opportunities to transform the existing engineering curricula for designers who have full authority. In Malaysian context, curriculum designers have some degree of liberty to make changes on the existing curricula. Designers have to address the university's aims and fulfill the requirements set by international and local accreditation bodies. Therefore, the implementation of the proposed principles for sustainability incorporation must be aligned with university aims and accreditation requirements.

iii) Redesign curriculum for incorporation

Once the strategies to incorporate sustainability have been laid out, a curriculum designer can redesign the existing curricula or design a new curriculum aligned with the new educational goals and aims. Depending on the existing curriculum structure, incorporation of sustainability affects several components in curriculum, such as learning objectives, learning materials and assessments methods. Therefore, incorporation of sustainability is not only by including a new topic or unit that is related to the concept of sustainability into the existing curriculum, but it entirely demands changes in other components of the curriculum. The changes on the curriculum also depend on to what extent the incorporation of sustainability is expected in the existing curriculum. For instance, if a designer decides to incorporate specific competencies that are related to sustainability in the course learning objective and expects students will obtain the competencies, he/she needs to redesign learning materials, restructure teaching approach and learning activities, and redesign assessment methods. These changes on curriculum could potentially give impacts on students learning outcomes. But if a designer only aims to increase awareness amongst students on the concept of sustainability and has no intention to assess the understanding, probably inserting a small discussion about the concept of sustainability as a part of learning materials could be sufficient. However, the impacts are possibly very minimal.

In this study, the strategies to redesign existing engineering curriculum include reconstructing learning objectives, planning several teaching strategies, designing learning activities, and developing assessment methods. In order to address the research questions, the strategies were developed by exploring real world practices and taking aspirations of two positive practices of sustainability incorporation in engineering education. It was also developed by adapting the employed curriculum model in most universities in Malaysia and particularly Universiti Teknologi Malaysia.

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Chapter 3

Research Methodology

3.1 Introduction

This chapter describes the operational framework of research methodology that has been designed to achieve the research objectives as well as to address the research questions. The chapter starts with a research paradigm which is presenting the adaptation of a basic design cycle into educational research methodology. The presentation of the chapter continues by clarifying the research methods and providing operational diagrams which consist of procedures and products for each of the research phases.

3.2 Research model

Figure 3.1 shows the research model which is purposely developed for this research. The research model was developed by adapting the basic cycle of design, analysis-design-develop-implement-evaluate. Due to the fact that the research objective is to develop a design framework to incorporate sustainability in engineering curricula, the basic design cycle guided the research process, where in this study the research processes are manifested in Figure 3.1. The research processes depicted in the research model consist of four phases. The alignment of the research phases to basic design cycle is depicted in the following Figure 3.2.

In the first phase, the framework for course design has been developed based on reviewing sustainability courses across continents and collecting feedbacks from experts and practitioners in sustainability for the means of real world practices and as a tool to develop instruments for the next phases. Two case studies have been conducted in the second stage (phase 2) of the research process. It is expected that an in-depth research of case studies should be able to point out the possible variables to develop evaluation tools and indicators as well as to redesign the framework of the course design. Two of the phases, phase 1 and phase 2, focus on analyzing the elements included in a design framework and designing the framework.

The third phase is a descriptive study for course evaluation. At this stage, effectiveness of four selected sustainability courses has been evaluated and indicated. There are three types of evaluation tools used for measuring the sustainability courses, which are evaluation tools for knowledge, skills and attitudes of students. The tools use numerical values to represent level of learning outcomes acquired from the courses. This descriptive study is intended to evaluate the offered sustainability course without intervention on the existing course design. Therefore, the real world practice can be justified and be part of solutions to achieve the research objective, which is to develop a design framework of course design.

The final phase is aimed to validate the proposed framework of course design. The framework has been tested to redesign the existing engineering course in order to incorporate sustainability. A group of university teachers (the respondents) were assigned for the tests. A short two-day workshop was conducted to introduce the proposed framework of course design to the respondents. In the workshop, the respondents have opportunities to use the framework to redesign their own engineering course(s), so that the sustainability can be incorporated. At the end of the workshop, all respondents have given feedbacks on the aspect of deliverability and practicality. Finally, all the respondents´ feedbacks have been analyzed and used as important inputs for improvement.

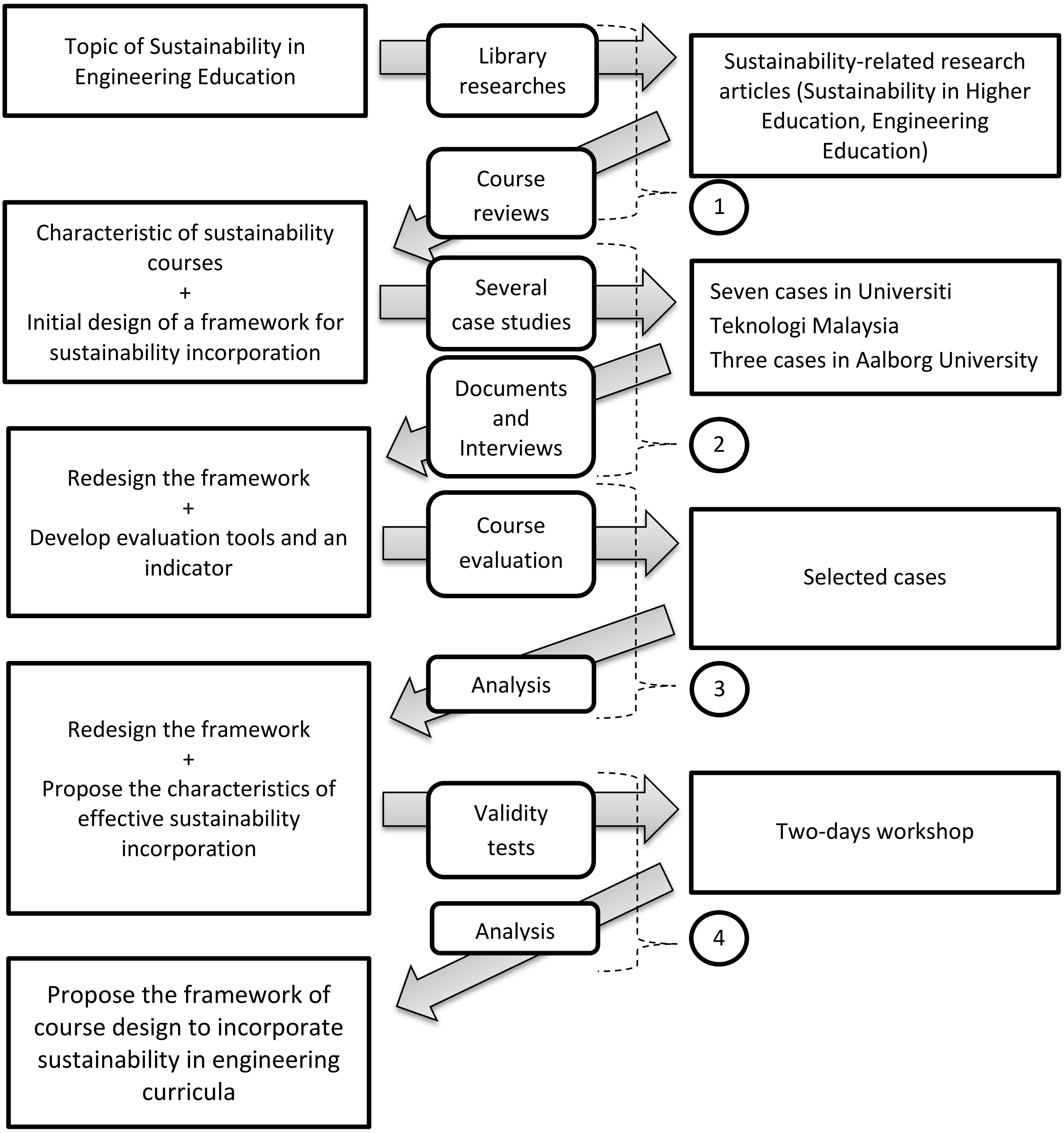

Figure 3.1 Research model

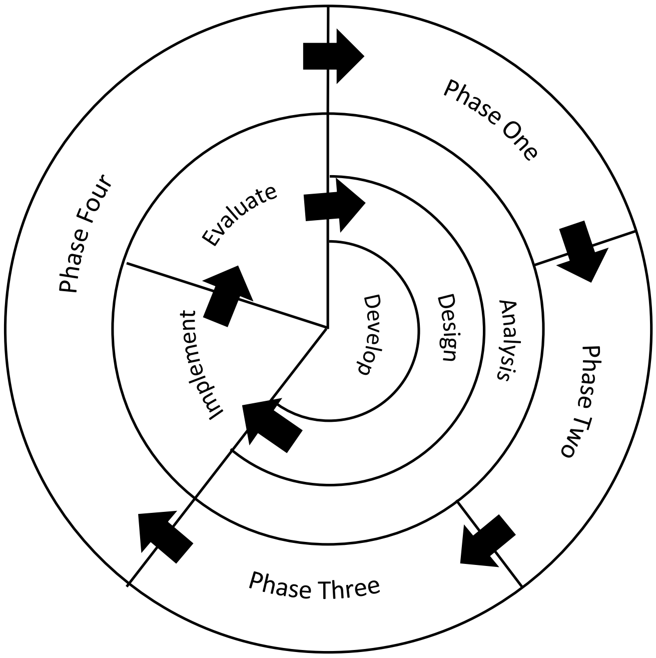

Figure 3.2 Alignment of research phases to basic design

The above figure demonstrates that the process of analysis, design and develop are taking place in phase 1, 2, and 3. The process is rather a dynamic process. This is due to the long process of analysis stage which starts from exploring the practices of sustainability incorporation around the globe (in phase 1) to the deep understanding of the practices from selected cases (in phase 2 and 3). Each phase contributes important inputs to the process of designing and developing a framework to incorporate sustainability in engineering curricula. Therefore, the researcher has to refine the design if there is a new input emerging from the analysis or the researcher has to study in a more in-depth manner if the design is incomplete. In the last phase, the output from the development process has been implemented and finally evaluated. The cycle of research phases has been brought back to phase 1 if the results from the evaluation do not satisfy the research objectives.

3.3 Phase One: Exploring real world practices

Figure 3.3 depicts the exploratory mixed methods design (Creswell and Clark, 2007) that was used to address research problem (i) and executed in phase one of the overall research model. The outcomes from phase one provides preliminary knowledge and perspectives based on ten components of sustainability in engineering education. Later in phase four, the outcomes will rationalize the framework for designing sustainability course.

This exploratory mixed methods design aims to get an overview of sustainability in engineering education and practical point of views on how higher institution incorporate sustainability in engineering curricula and the conceptual point of views on the principles and concepts of sustainability in engineering education. In the initial state, a total of 34 articles including journal articles, conference papers and online documented engineering courses have been collected through a systematic data gathering. For the purpose of identifying the strategy to incorporate sustainability in engineering curricula, sustainability courses were analyzed by reviewing thirteen published articles, one internal document and nine online documented engineering courses. Table 3.1 presents a list of documents reviewed in understanding the experiences of higher institution in incorporating sustainability in the curriculum.

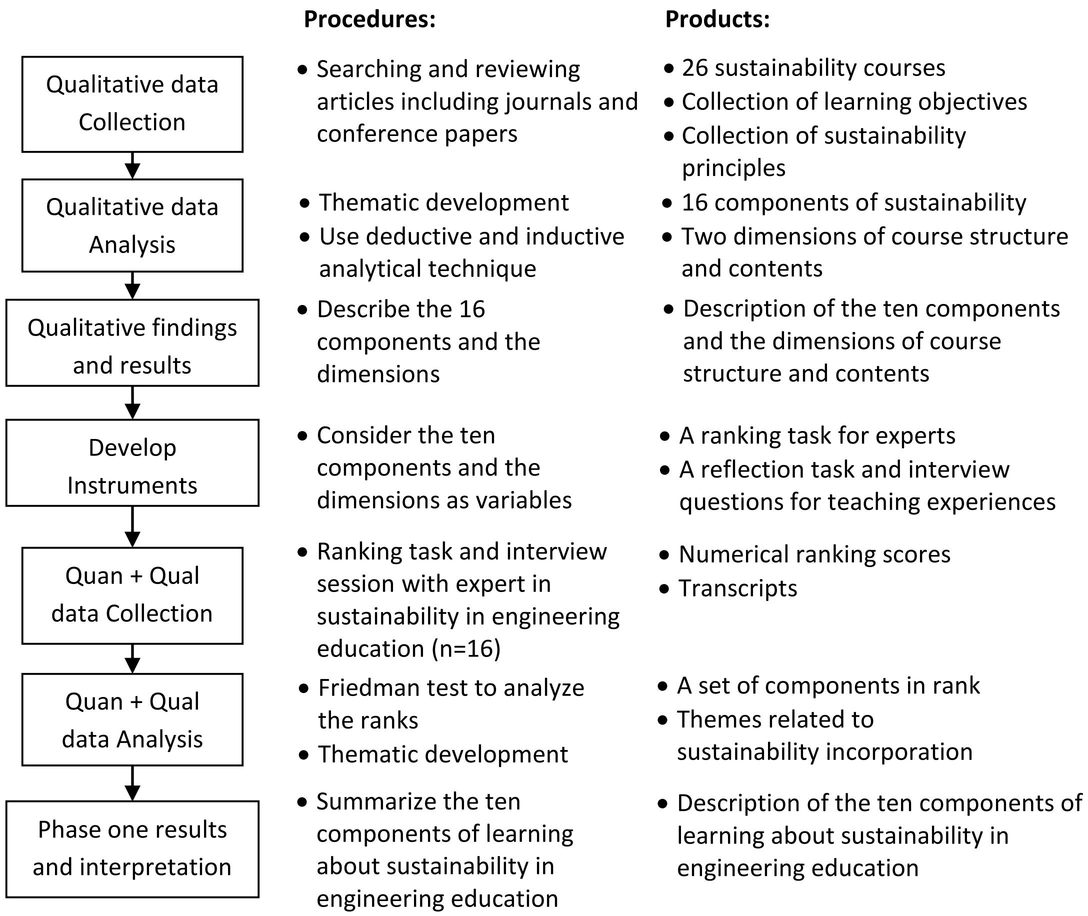

Figure 3.3 Phase one – exploratory mixed methods design

Table 3.1 List of sustainability courses

No	Title of Course/Article	Source
1	Sustainable design and construction	International Conference on Engineering Education in Sustainable Development
2	Sustainable civil infrastructure systems	
3	Design 5	Journal of Cleaner Production
4	Applied Sustainability and Public Health in CE Design	Journal of Professional Issues in Engineering Education and Practice
5	Ecological Engineering 2	Journal of Engineering Education
6	Business, Society and Environment	Journal of Cleaner Production
7	Sustainable development and responsibility	AAU internal documents
8	Environmental Principles for Sustainable Design	Proceedings of the 2005 ASEE
9	Education and Awareness for Sustainability	International Journal of Environmental & Science Education
10	A Sustainable Development Course for	International Journal of Sustainability in

	Environmental Engineers in Kyrgyzstan	Higher Education
11	Engineering Clinic	Proceeding of the 2002 ASEE
12	Introduction to Engineering Practice	Proceeding of the 2010 ASEE
13	Engineering Analysis and Problem Solving	Proceeding of the 2007 ASEE
14	Climate, Sustainability and Society	20th Australian Association for Engineering Education Conference
15	Materials and Resources	CEBE Transactions
16	Sustainable Cities and Urban Regeneration	
17	Environmental Challenges and Leadership in Asia	The University of Tokyo online document
18	Sustainable Process Development	National University of Singapore online document
19	EEWS Technology and Commercialization Perspectives	KAIST online documents
20	Environmental Studies	University of Mumbai online document
21	Ubiquitous Sustainable Engineering	POSTECH online document
22	Engineering for Sustainable Built Environment	Hong Kong University online documents
23	Sustainability Technology Evaluation and Theory	Osaka university online documents
24	Global Threats and Sustainability	
25	Understanding Environment, Development and Sustainability	Chulalongkorn University online documents
26	Ecological Engineering Practices	National Taiwan University online documents

Chapter 5 presents the analysis of the principles and the concepts of sustainability based on nine published articles and two online documents. The articles or documents were selected to provide understanding on the requirement needed to achieve sustainability and the details components in relation to sustainability in engineering education as well as engineering as a profession. The analysis includes a discussion on the concepts and principles of sustainability in engineering education and sustainability in engineering. The materials of the analysis are depicted in the following table.

Table 3.2 List of studies on concepts and principles of sustainability

No	Title of Article	Source
1	A knowledge map for describing variegated and conflicts domains of sustainable development	Journal of Environmental Planning and Management
2	Sustainability: Principles and practice	A chapter in Sustainability critical concepts in the social sciences
3	Ethics, engineering, and sustainable development	IEEE Technology and Society Magazines
4	Green engineering: defining the principles – results from the Sandestin conference	Journal of Environmental Progress
5	Engineering for sustainable development: Guiding principles	The Royal Academy of Engineering
6	Sustainability principles and practices for engineers	IEEE Technology and Society Magazines
7	Widening engineering horizons: addressing the complexity of sustainable development	Proceedings of the Institution of Civil Engineers: Engineering Sustainability

8	Declaration of Barcelona	Online document from International Conference
9	Graduate attributes and professional competencies	Online document from International Engineering Alliance
10	Engineers, society and sustainability	A book entitled Engineers, Society, and Sustainability
11	Sustainable development in engineering education	Journal of Industry and Higher Education

The qualitative data (the sustainability courses and articles related to sustainability concepts and principles) were collected from online data bases and the data were analyzed thematically. In this process, two sets of concepts regarding sustainability in engineering education were developed including the three dimensions of sustainability course and ten components of sustainability; and both concepts were converted to research instruments.

The research instruments were designed into two types, one as a ranking task (quantitative approach) and another one as a reflecting task (qualitative approach). The ranking task instrument was designed to identify sustainability experts´ stance on concepts of sustainability in engineering education, whereas the reflecting task is designed to understand experts´ justification on the concepts of sustainability in engineering education. The participated experts were divided into three groups, two groups were from Universiti Teknologi Malaysia, Malaysia and Aalborg Universitet, Denmark, and another group was experts from various countries such as The Netherland, India, Spain and Switzerland. The experts´ background also varies in engineering disciplines.

The selection process of the experts in the field of sustainability in engineering education can be depicted in Figure 3.4. The process begins by screening experts in the field of sustainability in higher education. Initially, the screening started by focusing on the editorial board of International Journal of Sustainability in Higher Education, where the experts are amongst scholars in higher education. From there the operation for selecting experts began and the selection amongst university experts in Universiti Teknologi Malaysia and Aalborg Universitet began simultaneously. The interview sessions for the ranking task and the reflection task were set at the same time the invitation emails were distributed. Once the invitations have been accepted, the interview sessions (from one expert to others) continue until the interviewer felt that there is no new information/data coming from interviewee. Figure 3.4 also shows that the samples of the session will grow as the process continues.

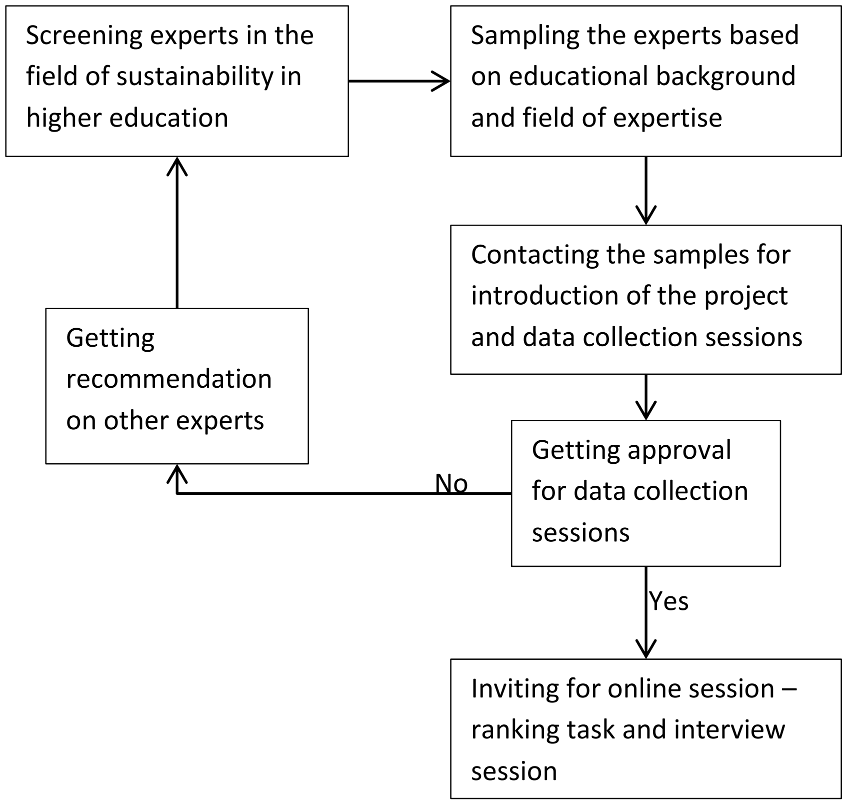

Figure 3.4 Operational diagrams for expert selection

As a result of the selection process, a total of 17 experts in the field of sustainability participated in phase one. The research in phase 1 had started on February 2012 and had ended on December 2012. Eight participants were from Universiti Teknologi Malaysia, four participants were from Aalborg Universitet and five participants were from other universities.

3.4 Phase two: Highlighting positive practices

In the second phase, this study has used a qualitative approach in addressing research problems ii. The study was divided into several cases, as examples of sustainability incorporation in engineering curriucla some selected cases were in Universiti Teknologi Malaysia and some selected cases were in Aalborg Universitet. These cases were selected to represent the four major engineering fields (Civil, Mechanical, Electrical and Chemical engineering) and sustainability courses, a variety of pedagogical strategies and the results from the cases will be complementing one another. The qualitative data began with reviewing engineering programs offered at both universities either in undergraduate programs or postgraduate programs. All study cases depend to a large extend on the collaboration of the teachers. As a result from the extensive qualitative data analyses from Universiti Teknologi Malaysia (UTM), seven cases were found to have met a point to be further studied in-depth and three cases from Aalborg Universitet (AAU). In order to have a smooth session of data collection, preparation of the research instruments is important and upfront agreements with prospective university have been made including with every level of organization, Dean of school, Head of Department, Course Coordinator and teachers. Figure 3.5 shows the qualitative research design in phase two.

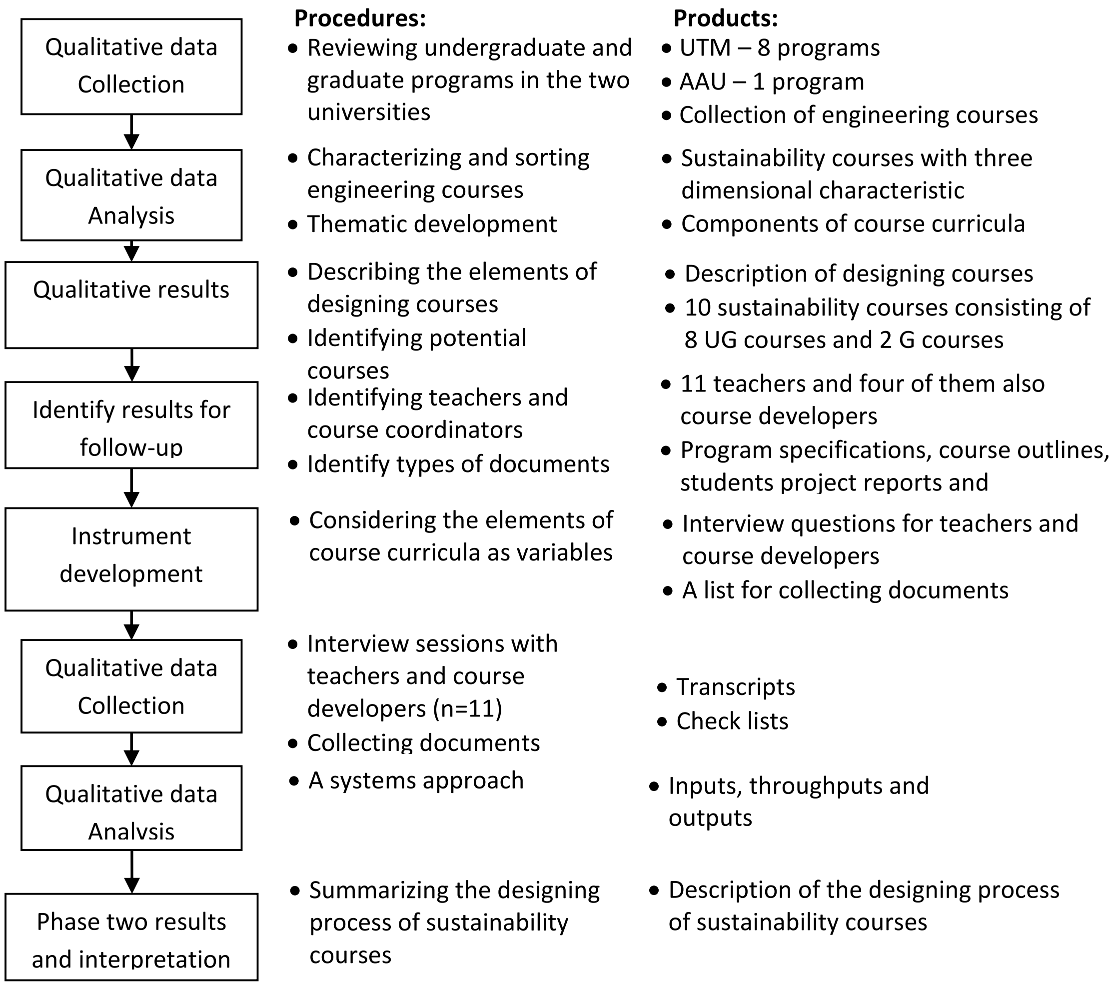

Figure 3.5 Phase two – qualitative design

The case studies in UTM were conducted for three months which commenced from 20th February 2012 until 19th May 2012 and the case studies in AAU commenced from September 2012 until November 2012. The collections of data started off by inventorying the programs offered at both universities. Eight programs in UTM were identified as having characteristics of sustainability course with four programs in AAU. This was validated by course coordinators through feedback on a course inventory. Figure 3.6 depicts the qualitative data collection process.

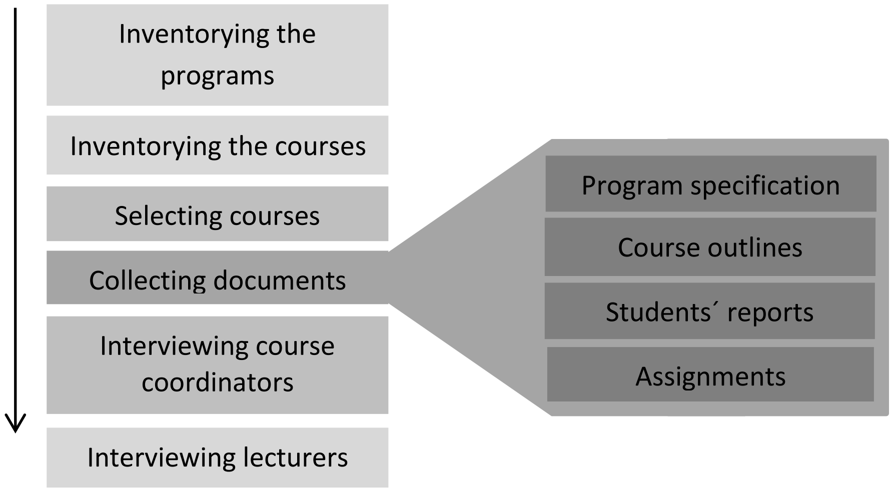

Figure 3.6 Qualitative data collection process

After the programs and courses have been selected, the researcher had sent an invitation letter to the respective teachers for each of the programs and courses to participate in this study. The researcher managed to have seven engineering courses from UTM and three engineering modules from AAU for the case study. Table 3.3 shows a list of the courses for the case study. It explains that there are four major engineering program that have participated in the study, which are Civil engineering, Mechanical engineering, Electrical engineering and Chemical engineering (in this case the program is called Petroleum engineering).

Table 3.3 List of the participated engineering courses

University	Program	Course (Case)
Universiti Teknologi Malaysia	Bachelor of Petroleum Engineering	Introduction to Engineering
		Plant Design
	Master of Civil Engineering	Sustainability and Environmental Management in Construction
	Bachelor of Civil Engineering	Civil Engineering Fundamentals
		Environmental Management
		Offshore Structural
	Master of Mechanical Engineering	Sustainable Manufacturing and Product Life Cycle
Aalborg Universitet	Bachelor of Electronics and Electrical Engineering	Technological Project
		Basic Electronic Systems
		Dynamic Electronic Systems

Each of the selected courses was studied in-depth in term of the course development strategies, teachers’ experiences of teaching sustainability in engineering education and students´ understandings of learning sustainability. As the first step of the in-depth study, document analyses were administered to collect course outlines, students´ reports and assignments. The strategies of course development in the perspective of educational philosophy and from a pragmatic point of view were also clarified during the interview sessions with the course coordinators. Therefore, the research question to understand the consideration taken by both universities to incorporate sustainability was also addressed.

The following Figure 3.7 shows the research model of the case studies, demonstrating from the left to the right, the alignment of three components consisting of research variables, data collection techniques and expected research outcomes. The upper part of the research model depicts how the research leads to the development of framework for designing sustainability courses while the lower part shows how the study will develop evaluation tools and indicators for sustainability in engineering education. A study on the teaching and learning of sustainability in engineering education has provided reliable information and trusted data. Teachers and course coordinators are two groups of experts that are deemed as essential to understand the strategy of curricula design undertaken by universities. For instances, qualitative data such as teachers´ experiences on teaching sustainability courses and course coordinators´ design experiences are highly significant to the study. In pragmatic perspective, these data also provide important elements in developing the main structure of the framework for sustainability incorporation.

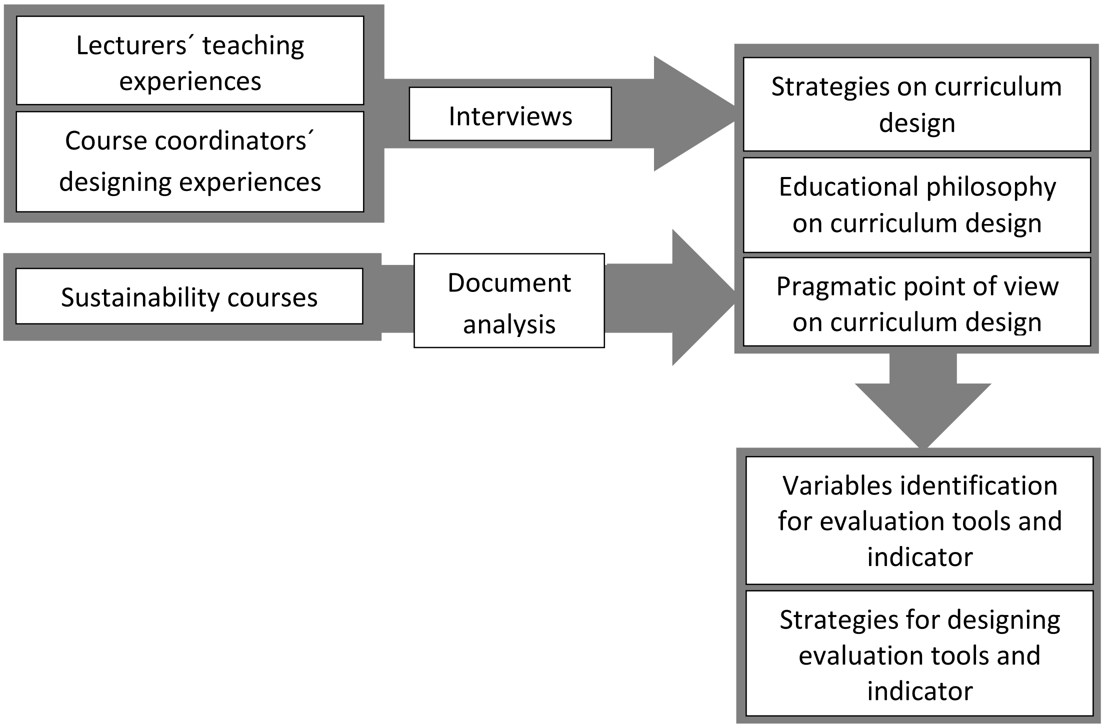

Figure 3.7 Research model for case studies

3.5 Phase three: Evaluating course effectiveness

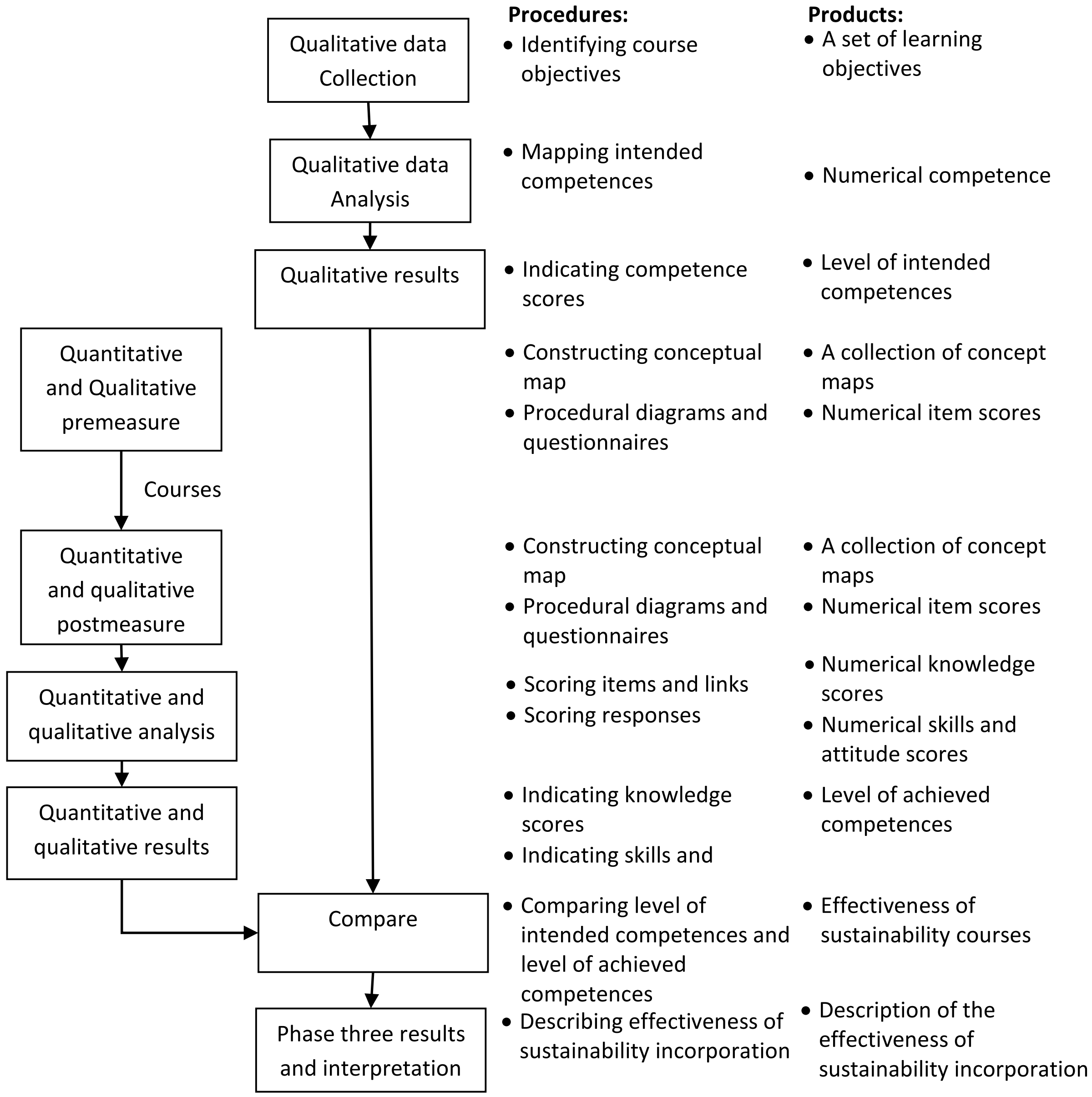

Figure 3.8 Phase three – mixed methods design

The objectives of phase three is to evaluate the effectiveness of sustainability incorporation and to understand the factors that contribute to the student learning outcomes in the implementation of selected engineering courses (see Table 3.3) from both universities, UTM and AAU. The research outcomes will provide the answer to the question of to what extent students are achieving the learning objectives in terms of their knowledge, skills and attitudes on sustainability. The outcomes also will identify the factors that contribute to the learning and the learning outcomes. For this purpose, the mixed methods design for phase three will address the third and fourth research questions mentioned earlier in Chapter 1.

A triangulation mixed method design (Creswell and Clark, 2007) was used as the main design in evaluating the teacher´s expectations and student learning outcomes, on the other hand qualitative design was used to evaluate learning objectives from researcher's point of views. Student´s attitudes have been evaluated quantitatively through questionnaires while student's competencies such as skills and knowledge of sustainability have been evaluated qualitatively through conceptual maps and procedural diagrams. This phase had carried on for three months from March until May 2013. Figure 3.8 demonstrates the procedures and expected products in the phase three mixed methods design.

The participants of this study have been selected by using criterion sampling as the research sampling method. Based on a study by Patton (1990), there are several sampling methods that can be found in the purposeful sampling such as intensity sampling, maximum variation sampling and etc. The characteristic of criterion sampling that permits the researcher to state the criterion for the selection of participants is the main reason to apply the method in this study. Therefore, the research outcomes are useful to identify the factors that contribute to the learning and can provide understanding in the effects of the approaches taken for incorporating sustainability in engineering curricula. The criteria of case/participant are shown in Table 3.4.

Table 3.4: Criteria of samples

Type of case/participant	Criteria	Considerations
Engineering course	Incorporate sustainability	The outcomes will be highly relevant to the aims of the research
	Participated in the phase two of the research process	The outcomes will provide an understanding on the effects of the strategy taken from the previous phase.
Students	Undergone the learning process on the participated engineering courses	Comparison of the course effectiveness will be fair and the research outcomes will be valid (the data was invalid if the students failed to go through the learning process)

3.6 Phase four: Validating design framework

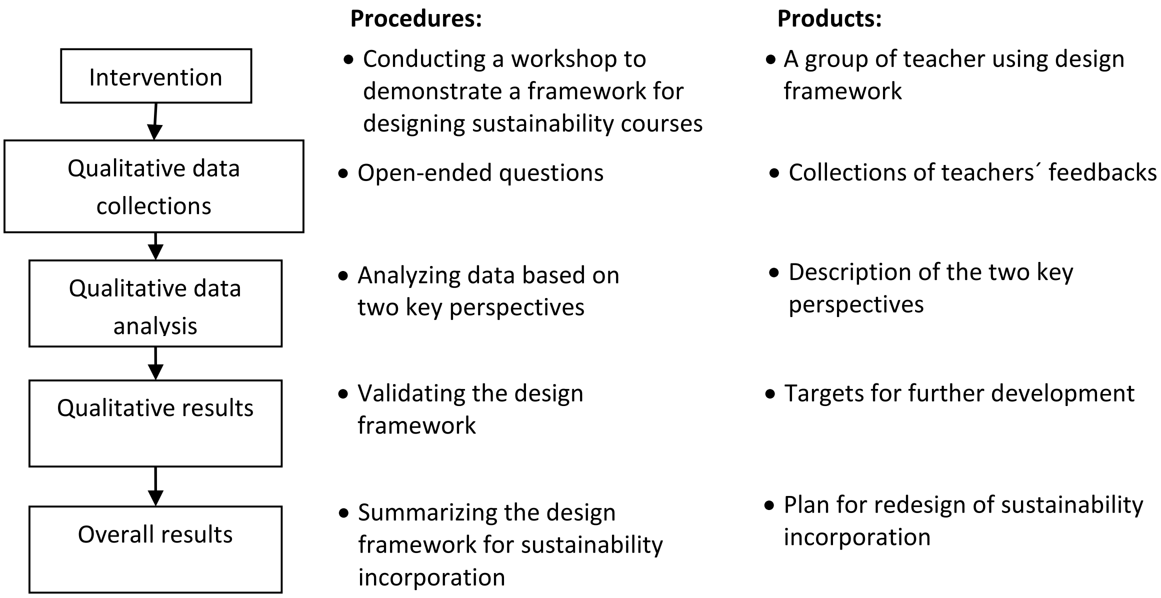

Figure 3.9 Phase four – pre-experimental design

The final phase of this study is to validate the design framework as depicted in Figure 3.9 and executed on July 2013. The framework was presented to a group of teachers in a workshop for developing a sustainability course. In this workshop, the teachers used the framework and worked together with facilitators to see how the framework works. The participants (the teachers) were selected based on the requirements set for using the framework. The participants have to be familiar with concepts of sustainability and course design. The participants also have been selected amongst the teachers who have participated in the previous two phases. Selecting participants that have knowledge about the concepts of sustainability and course design would give reliable feedbacks on the proposed framework to incorporate sustainability into the existing engineering curricula. Therefore, they would give feedbacks on the proposed framework by addressing the aspect of deliverability and practicality.

3.7 References

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Chapter 4

Development of research instruments and analysis techniques

4.1. Introduction

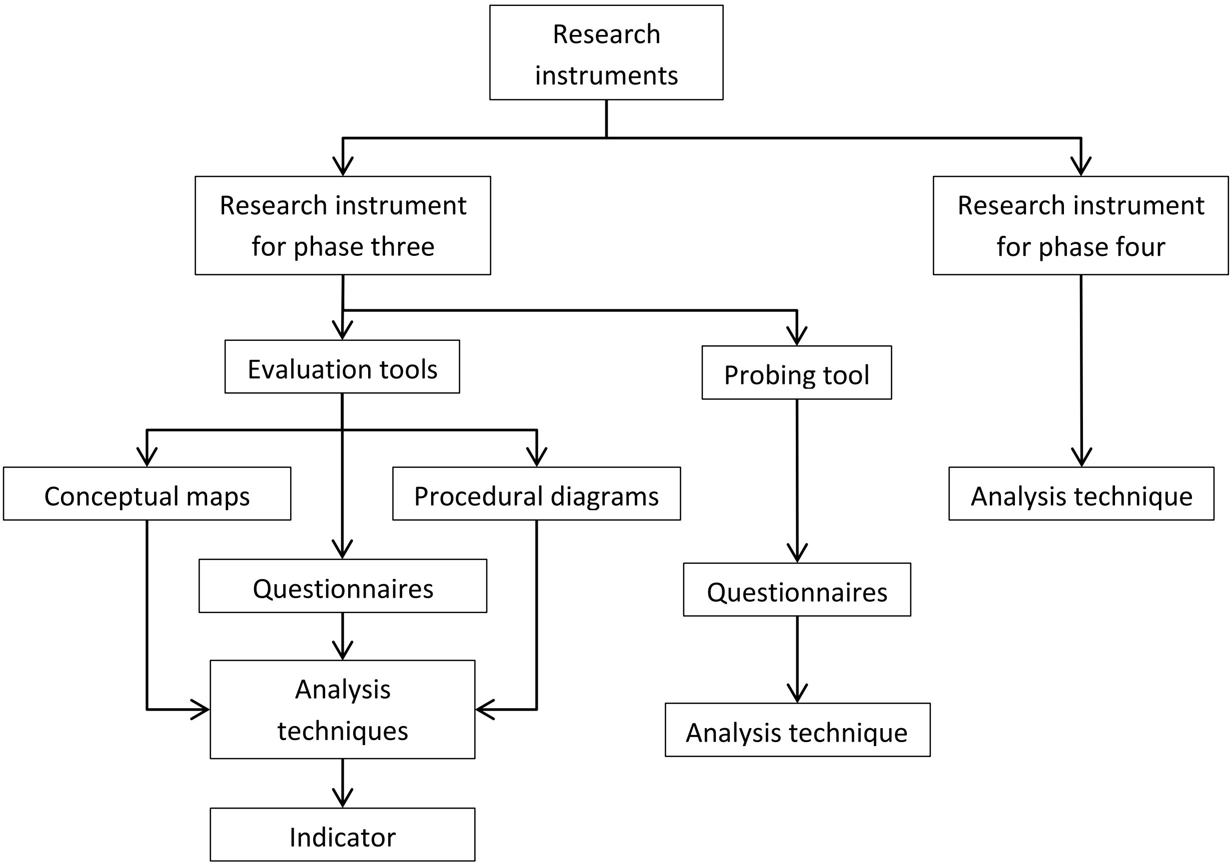


Figure 4.1 Discussion paths for chapter 4

The discussions in this chapter describe the process of developing research instruments and providing analysis techniques for both research phases, phase three and phase four, of the project. The discussion begins with describing the process of developing evaluation tools for the study to measure the effectiveness of the courses. The tools are conceptual maps, procedural diagrams and questionnaires. Next an overview of the analysis techniques needed for interpreting the data and transforming the data in terms of effectiveness by applying the developed effectiveness indicator are provided. This chapter will also discuss the development of the questionnaires as a probing tool and how it can be analyzed. Later in this chapter, the researcher will focus on the process of developing the research instrument for phase four and the analysis technique. It is a tool to get feedbacks on the proposed framework to incorporate sustainability in engineering curricula. The following Figure 4.1 illustrates the discussion paths for this chapter.

4.2. Research instruments

The previous chapter (see Chapter 3) explains that there are four research phases designed in adapting the basic cycle of design for developing a framework to incorporate sustainability in engineering curricula. The chapter also explains that each of the phases is important to the development process and each of the phases addresses different research questions. For the purpose of collecting data, each of the phases has dissimilar approaches in terms of the data collection techniques and research instruments.

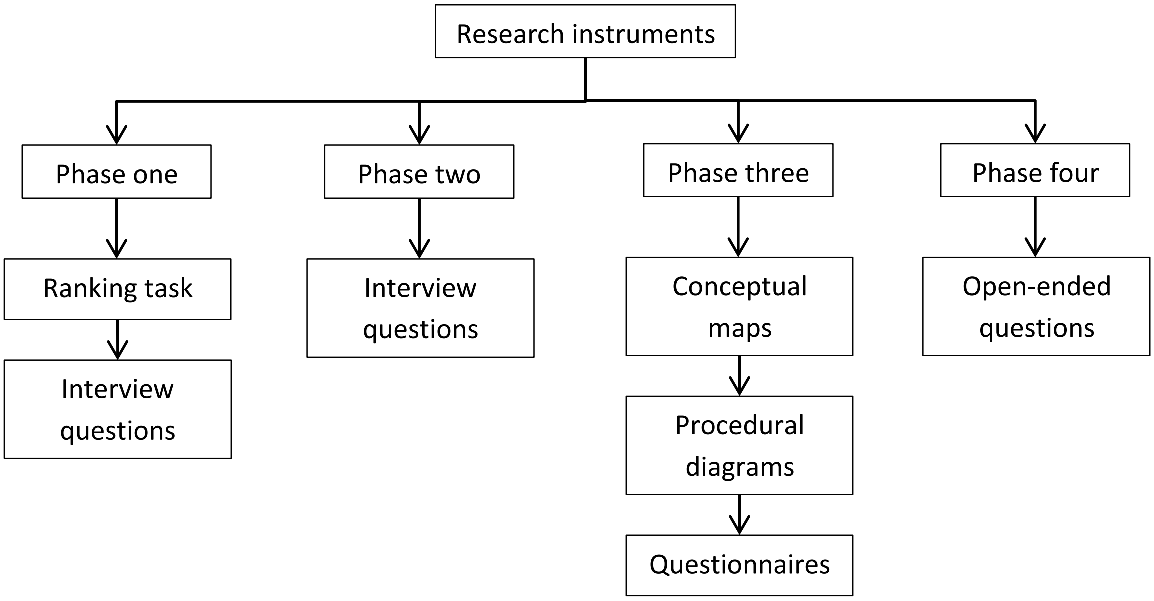


Figure 4.2 Research instruments for four research phases

In phase one, the research instruments were developed in two formats. The first format is a ranking task, and the second format is a set of interview questions (see chapter 5 for further explanations). The development of the research instruments is based on the research findings during the previous research process. Results of reviewing several sustainability courses in engineering disciplines and the principles of sustainability in engineering education served as inputs for the development process. In phase two, it was decided to develop a set of interview questions as a research instrument to elicit teacher´s experiences in designing sustainability courses and implementing the sustainability courses. The interview questions were developed on the base of the interview questions in phase one and the findings from the programs and course inventories in both case studies (see chapter 6 for further explanations).

The main research objective for phase three is to evaluate the effectiveness of sustainability incorporation and the factors that contribute to students learning outcomes for the selected sustainability courses offered in both universities. The evaluation is based on the students' competencies which comprise the knowledge, skills and attitude of students towards sustainability. In order to evaluate the students´ competencies, the research had used three different methods according to the competencies. The students´ understanding on the knowledge of sustainability was evaluated by using conceptual map as a tool. Whereby the students´ skills were evaluated by procedural diagrams and the students´ attitude towards sustainability were evaluated by using a set of questionnaires.

In phase four, the teachers´ feedback on the deliverability and practicality aspects of the proposed framework was collected via open-ended questions. The questions were posed at the end of phase four where at the earlier of the research phase, the researcher explained the proposed framework. By getting the feedback on the end product of the research (the proposed framework), this evaluation process of the proposed framework completes the basic cycle of design.

However, this chapter will be limited to the description of the process of developing research instruments for phase three and phase four. This is due to the process of developing research instruments for phase one and phase two which include most of the discussions and findings of the research phases itself. Therefore, the process of developing the research instruments for both phases will be further explained in Chapter 5 (for phase one) and Chapter 6 (for phase two). The research instruments for both phases are attached in Appendix B.

4.3. Research instruments for phase three

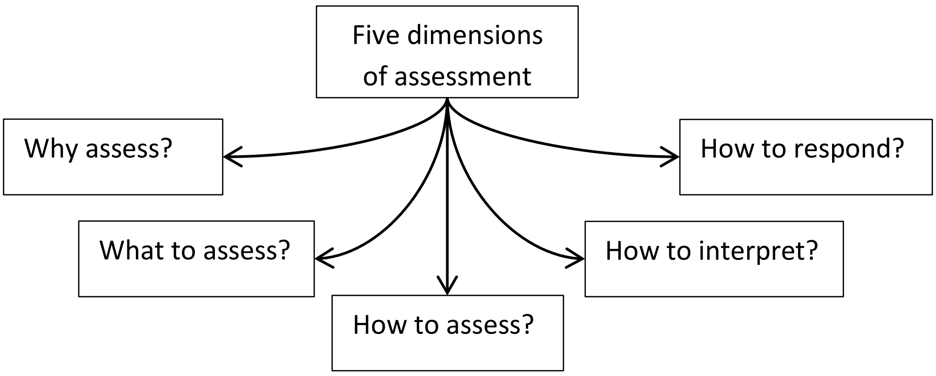


Figure 4.3 Five dimensions of assessment

In general, the purpose of assessment is for selection, maintaining standard, motivation of students, feedback to students, feedback to the teacher and preparation for life. The construction of the assessment tool for assessing sustainability skills is based on the framework introduced by Rowntree (1987) in Figure 4.3. The framework outlines five dimensions of assessment.

Rowntree (1987) explains the dimensions as the followings:

- Why assess? – *Deciding why assessment is to be carried out; what effect or outcomes it is expected to produce.*

- What to assess? – *Deciding, realizing, or otherwise coming to an awareness of what one is looking for, or remarking upon, in the people one is assessing.*
- How to assess? – *Selecting, from among all the means we have at our disposal for learning about people, those we regard as being most truthful and fair for various sorts of valued knowledge.*
- How to interpret? –*Making sense of the outcomes of whatever observations or measurements or impressions we gather through whatever meaning we employ; explaining, appreciating, and attaching meaning to the raw `events´ of assessment.*
- How to respond? – *Finding appropriate ways of expressing our response to whatever has been assessed and communicating it to the person concerned (and other people).*

Evaluation tool - Conceptual maps

Conceptual maps are tools that are graphically used to organize and represent knowledge (Novak and Cañas, 2008). The purposes of conceptual maps in learning are to identify students´ knowledge Lourdel et al. (2007), to identify students´ learning and needs (Cakmak, 2010), to improve students´ ability to think and analyze as well as one of the techniques of effective learning (Cakmak, 2010). Furthermore, conceptual maps are not only a tool for learning but also a tool for evaluation (Novak and Gowin, 1984; Novak, 1990; Mintzes et el., 2000; Novak and Cañas, 2008). Conceptual maps have been used and adapted as assessment tools to assess students learning outcomes in particular in the cognitive domain (Rice, Ryan and Samson, 1998). Several studies that focus on sustainability in engineering education have used conceptual maps as assessment tools (Borrego et al. 2009), also reported in Segalas (2008) where the same conceptual maps have been adopted in studies by Ahlberg (2004) and Gregorio & Freire (2006).

Conceptual maps are graphical tools for organizing and representing knowledge. The main features of the conceptual maps are:

i) Concepts, which are usually enclosed in circles or boxes.
ii) Connecting lines, which link two concepts to each other
iii) Words on the line, which are referred to as linking words

A conceptual map always starts with a general concept. For example in Figure 4.4, *Engineering Education* is the general concept. It is in the top of the hierarchy of the concept. The more specific concepts are arranged in lower hierarchy, for this case are *Technical Skills* and *Soft skills/ General skills*. Both concepts are connected with arrows and *consist of* is the linking word.

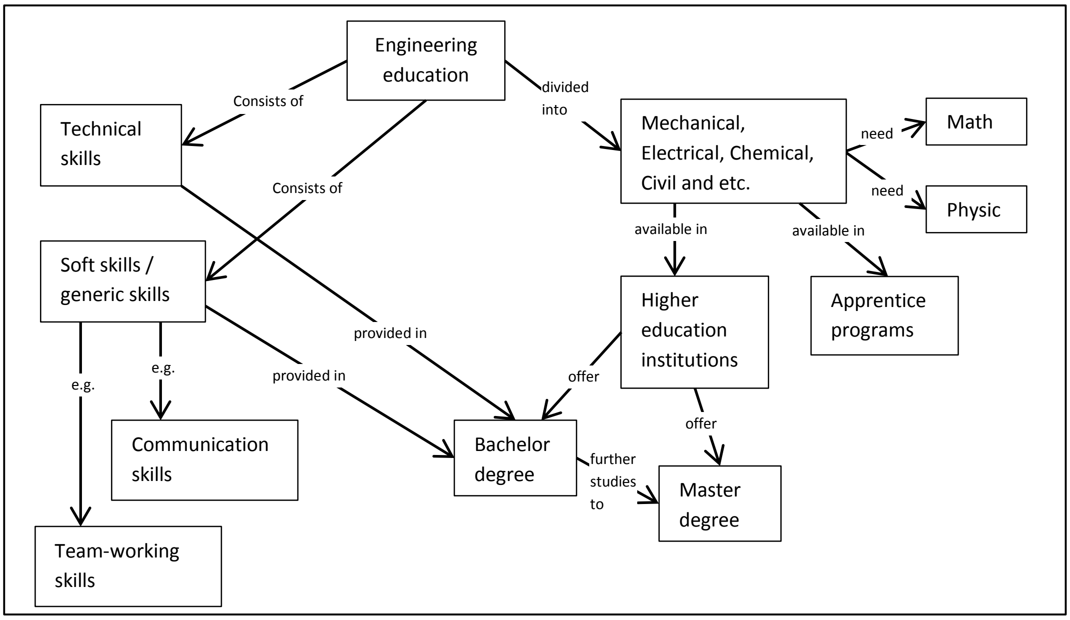


Figure 4.4 An example of Conceptual maps

Segalas (2008) identified four components that can be retrieved from the use of conceptual maps:

i) *The number of concepts*
ii) *The relevance of concepts*
iii) *The number of links*
iv) *The complexity of conceptual maps*

In a study by Lourdel et al. (2007), the researcher has stated seven possible objectives of using conceptual map as a tool:

i) *To evaluate the level of understanding of the concept*
ii) *To verify the dimensions of Sustainable Development that is perceived by the students*
iii) *To assess their ability to understand the relationship between various dimensions*
iv) *To represent changes in students´ knowledge structure over time*
v) *To visualize how they organize their knowledge in a new way* (Novak,1990)
vi) *To increase students´ awareness of learning process*
vii) *To check the outcomes of learning activities*

As a tool, conceptual maps can effectively work with analysis taxonomy as a companion. The characteristics of conceptual maps, variety of concepts, notions and forms, significantly require a detailed taxonomy that can be useful to analyze the conceptual maps. Table 4.1 is the example of taxonomy consisting of semantic categories that have been used in the analysis (Segalas, 2008).

Table 4.1 Example of taxonomy of analysis

UNESCO Chair in UPC	Lourdel (2004)	Segalas, Ferrer – Balas, Mulder (2008)
Environmental	Environmental	Environment
		Resources Scarcity
Social	Social cultural	Social impact
		Values
	Multidimensional approaches	Future generations (Temporal)
		Unbalance (Spatial)
Economic	Economic, Scientific, Technological	Technology
		Economy
Institutional	Procedural and political approaches	Education
	Actors and stakeholders	Actors and stakeholders

In this study, a taxonomy was developed based on literature reviews, document analyses and analysis on course learning objectives (collection of 118 learning objectives). As a result, 15 key components of sustainability are presented in Table 4.2 (see Chapter 5 for further explanation). The table shows that the elements of sustainability are categorized either in i) environment, ii) economic, iii) social, iv) environment-economic, v) economic-social or vi) environment-economic-social

Table 4.2 Taxonomy of analysis for Sustainability Concepts

<table>
<tr><th colspan="3">Sustainability pillars</th><th>Sustainability components</th></tr>
<tr><td rowspan="4">Environment</td><td rowspan="3"></td><td rowspan="5"></td><td>Environmental management</td></tr>
<tr><td>Environmental assessments</td></tr>
<tr><td>Resources</td></tr>
<tr><td rowspan="6">Economic</td><td>Green/Eco technology</td></tr>
<tr><td rowspan="8"></td><td>Economic (Profits)</td></tr>
<tr><td rowspan="10">Social</td><td>Quality in Engineering</td></tr>
<tr><td>Stakeholders</td></tr>
<tr><td>Social rights/value</td></tr>
<tr><td>Equity</td></tr>
<tr><td rowspan="3"></td><td>Citizenry</td></tr>
<tr><td>Culture</td></tr>
<tr><td>Empowerment of engineer</td></tr>
<tr><td rowspan="3"></td><td rowspan="3"></td><td>Holistic app/systemic app</td></tr>
<tr><td>Global issues</td></tr>
<tr><td>Local issues</td></tr>
</table>

For an evaluation tool, it is important to construct a conceptual map starting with a general concept which should be a concept that is familiar to the respondents and the person who constructs the conceptual map. In the study by Lourdel et al. (2007), one of the results from the use of conceptual maps has been highlighted as a tool that can evaluate students´ understanding of sustainability concepts which is,

> *"the terms that are used by the subjects to describe SD are different. These differences represent the varied representations of SD that may depend on people´s individual sensibilities, on their teaching experiences for the researchers but also on people´s values, attitudes and insights."*

Since the construction of conceptual maps is dependent on a person, therefore conceptual maps are context dependent. It is a manifestation of the respondent's understanding on the general concept bounded by his discipline(s), field of expertise, beliefs and etc. According to Novak and Cañas (2008),

> *"A good way to define the context for a conceptual map is to construct a Focus Question, that is, a question that clearly specifies the problem or issue the conceptual map should resolve. Every conceptual map responds to a focus question, and a good question can lead to a much richer conceptual map."*

Confined with these characteristics, a focus question is a key to construct a conceptual map that represents the expected learning outcome (knowledge of sustainability) and the knowledge of sustainability acquired by the students. Therefore, the researcher has developed two sets of focus question for the research instruments. The first set is posed to the teacher of the sustainability course and the second set is posed to the students. A focus question for the first set is:

> *By using conceptual maps, **what are the expected knowledge (could obtain in your course) about sustainability that should be acquired by the students?***

A focus question for the second set is:

> *By using conceptual maps, **what do you understand with the term Sustainable Technology?***

The first question is directly asking the teacher of the course to describe the expected knowledge of sustainability by using conceptual maps. The teachers will respond by reflecting on their teaching and learning activities for that particular course. The second question on the other hand, is asking the students to construct a conceptual map that describes their understanding on the concept of Sustainable Technology. It is a general concept in which from the perspective of the researcher, the concept is contextualized to engineering field (the respondents´ background and discipline). In both sets of questions, the respondents are provided with fifteen components of sustainability as the key concepts to construct conceptual maps. The fifteen components of sustainability were derived from the study in the research phase one (see Chapter 5 for further explanation). The respondents have the liberty to either apply the provided key concepts or construct their own key concepts.

Evaluation tool – Procedural diagrams

A procedural diagram is a graphical tool for organizing and representing a set of procedure. It is a tool to interpret a procedure in the form of skills. In research phase three, procedural diagrams were adapted as an instrument to assess students´ skills on sustainability. The development of procedural diagrams as an evaluation tool is inspired by the use of conceptual maps on assessing students´ knowledge of sustainability. The main features of the procedural diagram are:

i) Skills, enclosed by boxes
ii) Connecting lines, linking two skills to each other
iii) Stages of design

The students´ skills on sustainability can comprise technical and non-technical skills. The level of skills also depends on the individual’s ability to apply these skills in engineering practice. Table 4.3 shows a long list of competencies derived (have been simplified and represented by researcher own words) from the research in phase one that include skills on sustainability. The list only represents a small portion of competencies by learning sustainability in engineering education. It is impractical for the research phase three to develop an instrument that demands clearly stated skills and skill levels such as rubric for assessing skills on sustainability.

Table 4.3 Sub-elements, sub-concepts and competencies of sustainability in engineering

Sustainability pillars			Sustainability components	Competencies (Examples)
Environment			Environmental management	• Reduce the use of materials and chemicals that accumulate in the environment • Value the environment • Manage waste • Eliminate waste products • Eliminate/minimize the use of hazardous material • Pollution precaution
			Environmental assessments	• Apply environmental impact assessment tools • Monetary valuations of the environment • Compensate pollution • Use life cycle thinking in engineering activities
			Resources	• Reduce material and energy intensity development • Conserve and improve natural ecosystems • Improve energy efficiency • Improve resource efficiency • Minimize depletion of resources
	Economic		Green/Eco technology	• Develop clean technology • Employ ecological design • Develop technology and systems that work across a range of different scales • Follow green engineering
			Economic (Profits)	• Reduce material costs • Minimize use of materials

				• Increase production efficiency
		Social	Quality in Engineering	• Improve efficiency of products
			Stakeholders	• Engage to stakeholders to identify problems and issues • Listen to demands • Actively engaged to stakeholders in developing of engineering solutions • Reflect on stakeholders views
			Social rights/value	• Consider the right of society to inherit sufficient to generate a level of welfare • Protect human health and well being • Provide public safety • Contribute to social context • Communicate effectively with society at large • Access legal issues
			Equity	• Balance between inter and intra generations equity • Equity in resources allocation • Equity between the poor and the rich • Equity in material growth • Equal right for development • Long time scale of impact • Equal opportunities to effected people • Reduce gaps • Acceptable quality of life • Value future as well as current generations
			Citizenry	• Engineer participates in decision making as citizens • Listen to the demands of citizens • Counselor to citizenry in general
			Culture	• Include the knowledge culture and relate it with technology • Contribute in different culture • Meet the needs of culture • Cognizant of cultures in engineering process
			Empowerment of engineer	• Gain full autonomy over decision making
			Holistic approach /systemic approach	• Balance environmental, social and economic factors • Seek balanced solutions • Problem solution based primarily on human needs and ecosystem viability • Integrate view of the aspects of social development, economic growth and environment protection • Adopt a holistic, cradle-to-grave approach • Systematic assessment of all relevant expenses
			Global issues	• Global environment discourse

				• Security, peace and trade, hunger, shelter and water
			Local issues	• Cognizant of local aspirations • Interact with locals • Identify potential impacts

Therefore, procedural diagrams can be used as a compatible tool for assessment purposes in this research phase. The comparable features between procedural diagrams and conceptual maps make it reliable to apply for assessing student´s skills on sustainability. In developing procedural diagrams, the person who constructs the diagrams will construct procedural diagram based on his/her understanding. He/she will construct a diagram from several skills that he/she believes necessary for the design process.

Unlike conceptual maps, the construction of procedural diagrams is based on the procedure to create engineering solutions. So in general, procedural diagrams are manifestations of an engineering design process. It is important to have an overview on the models of engineering design in order to understand more on the construction of engineering design process and have a comparison on the activities of design if there were similarities with a basic design cycle. This is due to the aims of the research instrument which is not only to be able to assess student´s skills but should be applicable for all engineering students across the disciplines and suitable for all students regardless of year of study. Therefore, adapting basic design cycle in the process of developing procedural diagrams is a practical way for these purposes.

Wilson (1980) has presented an iterative model of the engineering design process. The model consists of seven main elements which are input, five intermediate processes and output. The input is societal need, whereby the intermediate processes are recognize and formalize, compare, ideate and create, analyze and/or test, and market place. The output of the model can either be a product or prototype or process. Figure 4.5 depicts the model. The process of recognizing and formalizing are to identify statements of problem, functional requirements and constraints. These outputs of the process are important in the process of comparing attributes of the existing products, which are to identify either *"the attributes of an existing product satisfactorily meet the need, and the product solves the problem"* or *"the problem as stated is infeasible and must be reformulated or abandoned"* or *"the problem appears feasible, but all known products have deficiencies and new solutions are needed"*. It can be observed that Wilson´s model is compatible with basic cycle of design in terms of design activities.

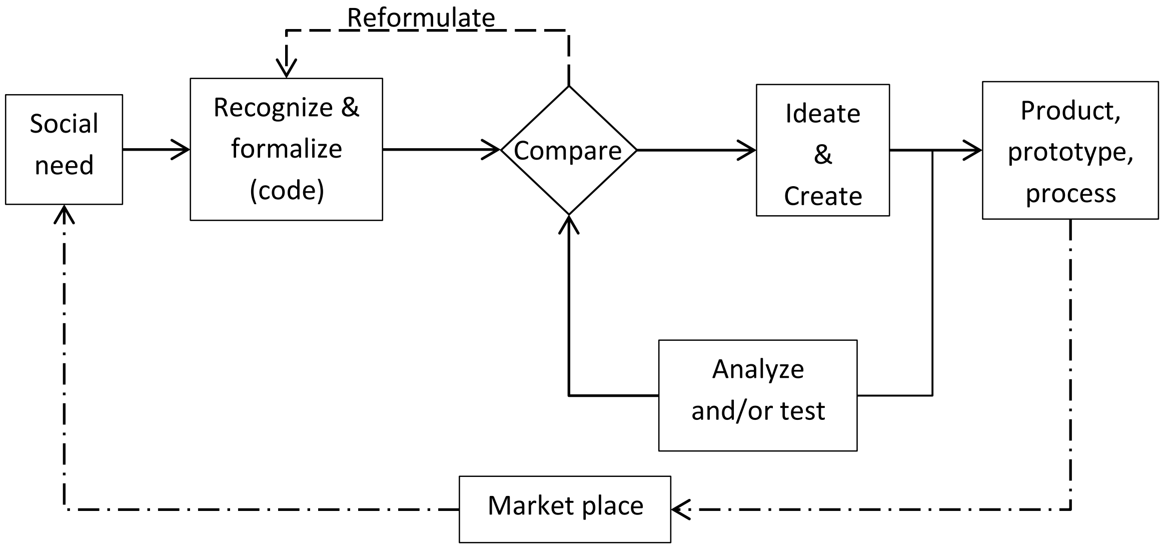


Figure 4.5 An iterative model of design

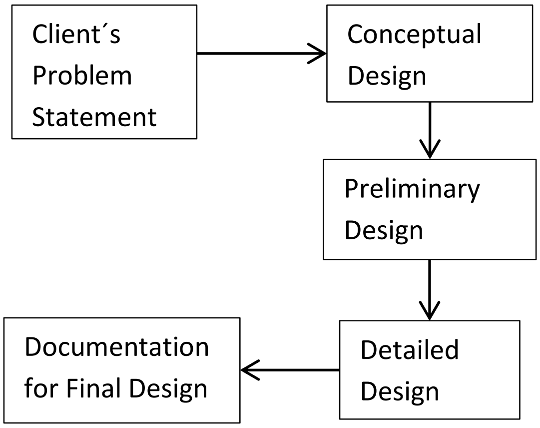
According to Dym *et al.* (2009), an engineering design process can be defined as three phases, i) generation, ii) evaluation and iii) communication. In the generation phase, the designer creates designs with various concepts, followed with evaluation phases where they evaluate the designs based on the functional requirements and client´s demands. In the last phase, the designer communicates with the client and manufacturers on the final design. In other design process, the cycle starts with i) doing research, continued with ii) creating and finally iii) implementing the design. In Dym *et al.* (2009), the design process is also presented in three other models. There are two linear models, i) three stages and ii) five stages design process. Figures 4.6a and 4.6b show both models respectively. Another model is presented as non-linear design process which includes feedback and iteration.

An extensive review of engineering design process which has been carried out by Howars, Culley and Dekoninck (2008) summarized that there are six common stages for engineering design process. The stages are i) establishing a need phase, ii) analysis of task phase, iii) conceptual design phase, iv) embodiment design phase, v) detailed design phase and vi) implementation phase. Table 4.4 depicts the common elements of engineering design process according to the study that has been conducted by them.

Table 4.4 Engineering design process models, (Howars, Culley and Dekoninck, 2008)

<table>
<tr><th>Models</th><th colspan="2">i</th><th colspan="2">ii</th><th colspan="2">iii</th><th colspan="2">iv</th><th colspan="2">v</th><th colspan="2">vi</th></tr>
<tr><td>Booz et al. (1967)</td><td colspan="2">-</td><td colspan="2">New product strategy development</td><td colspan="2">Idea generation, screening & evaluation</td><td>Business analysis</td><td colspan="2">Development</td><td>Testing</td><td colspan="2">Commercialization</td></tr>
<tr><td>Archer (1968)</td><td colspan="2">-</td><td>Programming</td><td>Data collection</td><td>Analysis</td><td>Synthesis</td><td colspan="2">Development</td><td colspan="2">Communication</td><td colspan="2">-</td></tr>
<tr><td>Svensson (1974)</td><td colspan="2">Need</td><td colspan="2">-</td><td>Concepts</td><td colspan="2">Verification</td><td>Decisions</td><td colspan="2">-</td><td colspan="2">Manufacture</td></tr>
<tr><td>Wilson (1980)</td><td colspan="2">Societal need</td><td>Recognize & formalize</td><td>FR´s & constraints</td><td colspan="2">Ideate and create</td><td colspan="2">Analyze and/or test</td><td colspan="2">Product, prototype, process</td><td colspan="2">-</td></tr>
<tr><td>Urban and Hauser (1980)</td><td colspan="2">Opportunity identification</td><td colspan="4">Design</td><td colspan="4">Testing</td><td>Introduction (launch)</td><td>Life cycle management</td></tr>
<tr><td>VDI-2222 (1982)</td><td colspan="2">-</td><td colspan="2">Planning</td><td colspan="2">Conceptual design</td><td colspan="2">Embodiment design</td><td colspan="2">Detail design</td><td colspan="2">-</td></tr>
<tr><td>Hubka and Eder (1982)</td><td colspan="2">-</td><td colspan="2">-</td><td colspan="2">Conceptual design</td><td colspan="2">Lay-out design</td><td colspan="2">Detail design</td><td colspan="2">-</td></tr>
<tr><td>Crawford (1984)</td><td colspan="2">-</td><td colspan="2">Strategic planning</td><td colspan="2">Concept generation</td><td colspan="2">Pre-technical evaluation</td><td colspan="2">Technical development</td><td colspan="2">Commercialization</td></tr>
<tr><td>Pahl and Beitz (1984)</td><td colspan="2">Task</td><td colspan="2">Clarification of task</td><td colspan="2">Conceptual design</td><td colspan="2">Embodiment design</td><td colspan="2">Detailed design</td><td colspan="2">-</td></tr>
<tr><td>French (1985)</td><td colspan="2">Need</td><td colspan="2">Analysis of problem</td><td colspan="2">Conceptual design</td><td colspan="2">Embodiment of schemes</td><td colspan="2">Detailing</td><td colspan="2">-</td></tr>
<tr><td>Ray (1985)</td><td colspan="2">Recognize problem</td><td>Exploration of problem</td><td>Define problem</td><td colspan="2">Search for alternative proposals</td><td>Predict outcome</td><td>Test for feasible alternatives</td><td>Judge feasible alternatives</td><td>Specify solution</td><td colspan="2">Implement</td></tr>
<tr><td>Cooper (1986)</td><td colspan="2">Ideation</td><td colspan="2">Preliminary investigation</td><td colspan="2">Detailed investigation</td><td></td><td></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Andreasen and Hein (1987)</td><td colspan="2">Recognition of need</td><td colspan="2">Investigation of need</td><td colspan="2">Product principle</td><td colspan="2">Product design</td><td colspan="2">Product preparation</td><td colspan="2">Execution</td></tr>
<tr><td>Pugh (1991)</td><td colspan="2">Market</td><td colspan="2">Specification</td><td colspan="4">Concept design</td><td colspan="2">Detail design</td><td>Manufacture</td><td>Sell</td></tr>
<tr><td>Hales (1993)</td><td colspan="2">Idea, need, proposal, brief</td><td colspan="2">Task clarification</td><td colspan="2">Conceptual design</td><td colspan="2">Embodiment design</td><td colspan="2">Detail design</td><td colspan="2">-</td></tr>
<tr><td>Baxter (1995)</td><td colspan="2">Assess innovation opportunity</td><td colspan="2">Possible products</td><td colspan="2">Possible concepts</td><td colspan="2">Possible embodiments</td><td colspan="2">Possible details</td><td colspan="2">New product</td></tr>
<tr><td>Ulrich and Eppinger (1995)</td><td colspan="2">-</td><td colspan="2">Strategic planning</td><td colspan="2">Concept development</td><td colspan="2">System-level design</td><td colspan="2">Detail design</td><td>Testing and refinement</td><td>Production ramp-up</td></tr>
<tr><td>Ullman (1997)</td><td>Identify needs</td><td>Plan for the design process</td><td colspan="2">Develop engineering specifications</td><td colspan="2">Develop concept</td><td colspan="4">Develop product</td><td colspan="2">-</td></tr>
<tr><td>BS7000 (1997)</td><td colspan="3">Concept</td><td>Feasibility</td><td colspan="7">Implementation (or realization)</td><td>Termination</td></tr>
<tr><td>Black (1999)</td><td colspan="2">Brief/concept</td><td colspan="2">Review of state of the art</td><td>Synthesis</td><td>Inspiration</td><td>Experimentation</td><td>Analysis/reflect</td><td>Synthesis</td><td>Decisions to constraints</td><td>Output</td><td>-</td></tr>
<tr><td>Cross (2000)</td><td colspan="2">-</td><td colspan="2">Exploration</td><td colspan="2">Generation</td><td colspan="2">Evaluation</td><td colspan="2">Communication</td><td colspan="2">-</td></tr>
<tr><td>Design council (2006)</td><td colspan="2">Discover</td><td colspan="2">Define</td><td colspan="3">Develop</td><td colspan="3">Deliver</td><td colspan="2">-</td></tr>
<tr><td>Industrial innovation process (2006)</td><td colspan="2">Mission statement</td><td colspan="2">Market research</td><td colspan="2">Idea phase</td><td colspan="2">Concept phase</td><td colspan="2">Feasibility phase</td><td colspan="2">Pre-production</td></tr>
</table>

The stages are representing the phases of the engineering design where each of the phases includes one or more activities of engineering design. The first two stages are establishing a need and analysis of task phases. They focus on activities such as analyzing the need of conducting the design, identifying the objectives of the design and clarifying the tasks. In the conceptual design phase, the design activities are more complex. At this stage activities of analysis, design and development have begun, not in a linear process, but more dynamically. It is where the key problems were identified, the functions of the design were established, and the economic criteria and technical criteria were evaluated.



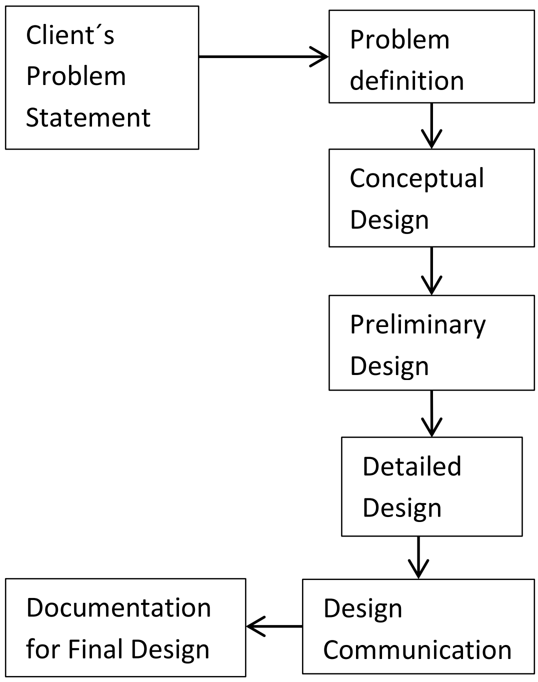


Figure 4.6a Three stages of the design process

Figure 4.6b Five stages of the design

process

Dynamic design activities were also applied in the stage of embodiment design. It is a stage where the conceptual design was developed to the next level. The designer started to develop a preliminary form or layout of the design, to make an analysis on the layout, and to refine the design in more details on economic and technical criteria. In this stage, the designer also conducts some form of evaluation as a test of the preliminary product, predicting the outcomes, running feasibility tests, and reflecting on the evaluation. In the detailed design, the final engineering solution is expected to be fully documented, which includes the complete detailed drawings and production documents, and describes all constraints of the engineering solutions.

The implementation phase is the final stage of engineering process. It is the stage to execute the engineering solutions either for pilot production or for a more advanced form of test. In this stage, the design activities are dynamic and complex; there are some feed forward engineering processes and feedback engineering processes. It includes activities of design, development, implementation and evaluation. Finally, at the end of this stage, the engineering solutions are ready for commercialization and production.

In order to adapt the engineering process into procedural diagrams as a tool for skills assessment, this study has simplified the six steps of engineering process proposed by Howars, Culley and Dekoninck (2008) into four steps of linear design stages (see Table 4.5). The procedural diagrams are structured by *analysis, design, develop* and *evaluate/testing* stages. In a linear design process, the respondents could state the process in the form of skills without spending a lot of time to understand the instruction and how the tool works. In fact, the complexity of the diagrams and the connectivity between the skills are disregarded in assessing students´ skills. The most important element is the attained level of skills. For assessment purposes, this study has introduced a five-point score as an indicator of the attained level of skills.

Table 4.5 Simplification of engineering design stages for procedural diagrams

<table>
<tr><td></td><td colspan="7">Stages of design</td></tr>
<tr><td>Howars, Culley and Dekoninck (2008)</td><td>Establishing a need</td><td>Analysis of task</td><td>Conceptual design</td><td>Embodiment design</td><td colspan="2">Detailed design</td><td>Implementation</td></tr>
<tr><td>Proposed design stages</td><td colspan="2">Analysis</td><td>Design</td><td colspan="2">Develop</td><td colspan="2">Evaluate</td></tr>
</table>

The respondents will always have to understand the given question and analyze the objective(s) to construct a procedural diagram. Similarly, the question is the key to represent the expected learning outcomes (skills) and the students´ skills on sustainability. Two sets of focus questions have been developed for these purposes. The question for the teacher to respond is:

> *By using a procedural diagram, please describe* ***what are the expected skills to be acquired by the students (that they could obtain in your course) in relation to development of a sustainable technology?***

And the question for students to respond is:

> *By using a procedural diagram, please demonstrate* ***how do you develop a Sustainable Technology?***

Both questions are posed differently but the aim is the same. The first question is asked to the teacher so that the teachers will respond to it in the context of the expected learning outcomes of the course. If the question is posed in the same way for the students, the teachers will respond entirely based on their understanding on the process of developing Sustainable Technology without concerning on the expected learning outcomes. Later in the analysis part it will cause invalid results.

After the objective is clarified, the respondents may start constructing their diagram by stating the very first step of the design process, for instance, Figure 4.7 shows that the first step of an *analysis* stage is the skill to *identify the problem background*. The next step of the process could consist of a single skill or more e.g. *Analysis of the problems using SWOT Analysis or Pro´s – Contra´s.* Both skills are connected with arrows. In hierarchal sense, the top skills are prerequisite for the skills below.

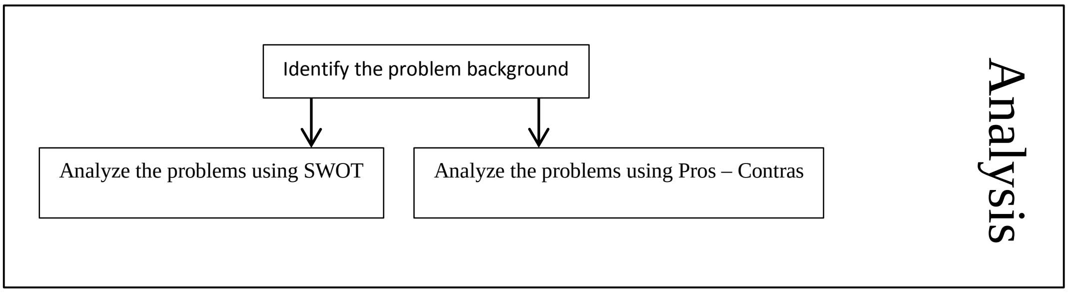


Figure 4.7 An example of procedural diagrams at analysis stage

After the procedural diagram is completed, the skills are self-rated by the respondents into five-point scores. The scores are:

Table 4.6 Five-point score for procedural diagrams

Score	Level	Description
0	Unskilled	Do not have experience of the skill.
1	Basic	Experienced in applying the skill on simple task.
2	Skilled	Experienced in applying the skill on difficult task.
3	Master	Experienced in applying the skill on complex task.
4	Expert	Experienced in applying the skill on sophisticated task

Evaluation tool – questionnaires

Two sets of self-administered questionnaires have been used in this study as a tool to assess students´ attitude towards sustainability and the teacher’s expectation on students´ attitude. The sets were entirely developed from 32 closed questions and built on the 15 components of sustainability in engineering education. The two sets of questionnaires that have been developed for this study are attached in Appendix B.5 and B.6.

The questions were constructed in such a way that the respondents have to visualize themselves as future engineers, and to reflect on their current attitudes towards the role of engineer as a profession in relation to the components of sustainability that are subjected in the questions. With five scales indicating the level of agreement, the respondents´ feedbacks on the scales represent their attitude by indicating their closest agreement to the statements. The respondents´ attitudes were measured on an ordinal scale. By checking the scale box, the respondents indicate and describe their attitude into non-numerical terms. The terms were represented in a Likert scale: strongly disagree, disagree, neutral, agree and strongly agree.

In the process of developing the questionnaires, this study defined the 15 components of sustainability in engineering education as the dependent variables (to be measured) while their role as an engineer in the future is the independent variable. As the questions were drafted, this study has applied a proposed guideline to design effective questions from the study of Fowler and Cosenza (2008) which is depicted by Table C.1 in Appendix C. In order to make sure the questions are constructed effectively, the researcher has conducted a systematic review on the questions and discussed with peers and supervisors in order to identify and improve problematic questions.

4.4. Analysis techniques for the evaluation tools

Analysis technique for conceptual maps

Conceptual maps are graphical tools that comprise concepts (or sub-concepts), connecting line and words on the line. In order to analyze the concepts drawn in the conceptual maps, each of the concepts (or sub-concepts) were coded according to the categories as demonstrated in the following table. For future reference, please use table D.1 in appendix D (folded version).

Table 4.7 Code of categories

Code	Category	Code	Category
C1	Environmental Management	C9	Citizenry
C2	Environmental Assessment	C10	Culture
C3	Resources	C11	Stakeholders
C4	Green/Eco Technology	C12	Empowerment of Engineer
C5	Economic	C13	Holistic / Systemic Approach
C6	Quality in Engineering	C14	Global Issues
C7	Social Rights/Values	C15	Local Issues
C8	Equity	C16	Others

The coded concepts were checked based on categories. The checked categories were later weighted with a score of one, regardless of the frequency (total number of coded concepts for that particular category) of categories. This statistical approach shows that it is not about the size of the sustainability knowledge or the complexity of the sustainability knowledge in that particular engineering course. Rather, the focus is on the availability of the course in providing the knowledge to the students.

To analyze the conceptual maps developed by the teacher, the researcher had to identify the stated sub-concepts and code the sub-concepts according to relevance of the categories. As long as the concept (or sub-concept) is mentioned in the conceptual maps and is linked to the main concept (in this case the main concept is Sustainability), the concept will be coded and checked according to its category. If the drawn concept (or sub-concept) is not from the provided categories, the concept will identify the relevancy to the categories. In other cases, if the concept is not related to the main concept it will be cut out but if it is related, it will be coded with code C16. The scores of each of the categories were converted in the form of index, where in this case, the values are either 1.0 or 0. The category that carried index value 1.0 demonstrates that the course provides the knowledge and the category with index value 0 indicates that the knowledge is not available and not provided.

The procedure to analyze the students´ conceptual maps is not much different from the procedure to analyze the teacher´s conceptual maps. The concepts and sub-concepts drawn by the students were also categorized and coded by taking Table D.1 as reference. Each of the students is individually analyzed, therefore the categories will get a score of 1.0 as long as the student mentioned them in his/her conceptual map. Later the scores for each of the categories will be counted and used as inputs to calculate the average score. The following table demonstrates the process to analyze students´ conceptual maps.

Table 4.8 An example analysis of conceptual maps

Respondent	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Respondent 1															
Respondent 2															
Respondent 3															
Respondent 4															
Respondent 5															
Total score of $C_{i\ (i=1\text{-}15)}$															
Samples N															
Index of $C_{i\ (i=1\text{-}15)}$															

Total score of $C_{i(i=1\text{-}15)}$ = Respondent 1´s score for C_i + Respondent 2´s score for C_i + Respondent 3´s score for C_i + Respondent 4´s score for C_i + Respondent 5´s score for C_i

The average score for each category can be formulated as follows:

$$MSi(C\text{-}Maps) = \sum \text{Score of } C_{i\ (i=1\text{-}15)} / N$$

Where;

$\sum$ Score of $C_{i\ (i=1\text{-}15)}$ is a total score for each of the categories

N is a total number of the respondents

The statistic formula for index value for each category is:

$$\text{Index of } C_{i\ (i=1\text{-}15)} = MSi(C\text{-}Maps) \qquad \text{(Formula 7.1)}$$

Analysis technique for procedural diagram

The procedural diagram has been introduced in this study as a new tool in evaluating students´ skills related to sustainability. A procedural diagram is simpler than a conceptual map in terms of its form of hierarchy and procedures. In order to analyze a procedural diagram, each of the skills, e.g. communication skills and applying systems approach in planning, is coded into categories referring to Table D.1. Unlike the process of analyzing conceptual maps, the analysis of a procedural diagram not only represents the skills in the diagram, but also the score rated on that skill. As the skills are identified and coded, the total scores for that particular category are counted and the average scores are calculated as follows:

Total score of $C_{i(i=1\text{-}15)}$ = Respondent 1´s score for C_i + Respondent 2´s score for C_i +
Respondent 3´s score for C_i + Respondent 4´s score for C_i +
Respondent 5´s score for C_i

The average score for each category can be formulated as follows:

$$MSi(PD) = \sum \text{Score of } C_{i\,(i=1\text{-}15)} / N$$

where;

$\sum$ Score of $C_{i\,(i=1\text{-}15)}$ is a total score for each of the categories

N is a total number of the respondents

From the analysis of teachers´ procedural diagram, the average score will indicate the expected level of skills to be obtained by the students at the end of the course, whereby from the analysis of students´ procedural diagram, the score will indicate the actual skills level obtained by the students. Later, the average score for each of category is further analyzed by calculating the index values. The index value for Procedural Diagram can be calculated by using the following formula:

$$\text{Index of } C_i = \frac{MSi(PD)}{4} \qquad \text{(Formula 7.2)}$$

Where;

C_i is Category i (i = 1 to 16)

MSi(PD) is Procedural Diagam Mean of Score for category i (i = 1 to 16)

4 is a constant value which is the maximum score for skill level

Table 4.9 A sample analysis of procedural diagrams

Respondent	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Respondent 1															
Respondent 2															
Respondent 3															
Respondent 4															
Respondent 5															
Total score of $C_{i\ (i=1-15)}$															
Samples N															
MSi(PD)															
Index of $C_{i\ (i=1-15)}$															

The index values of the procedural diagrams describe the levels of skills (either the skills the students are expected to obtain, or the skills actually obtained by the students). The index value for skills can be interpreted as depicted in the following table.

Table 4.10 Skill levels based on index value

Index value	Level	Description
0.00 to 0.12	Unskilled	Do not have experience of the skill
0.13 to 0.37	Basic	Experienced in applying the skill on simple task
0.38 to 0.62	Skilled	Experienced in applying the skill on difficult task
0.63 to 0.87	Master	Experienced in applying the skill on complex task
0.88 to 1.00	Expert	Experienced in applying the skill on sophisticated task

Analysis technique for questionnaires

The survey was designed to measure the expectations of teachers (from their course) and students´ attitude towards sustainability as a future engineer. The responses of the survey is based on five-point Likert scales ranging from 1 (strongly disagree) to 5 (strongly agree). In order to analyze the outcomes of the survey, the questions are grouped into categories depicted in Table 4.11. The following table shows the items of the survey that have been clustered into 15 categories.

Table 4.11 Categories of items

Question number	Statement	Category
6s.	They will manage the foreseen pollutions	C1
6t.	Their aim is to eliminate all waste products	
6o.	They will apply environmental impact assessment tools	C2
6p.	They agree the pollution should be compensated in monetary value	
6l.	It is important for them to protect social rights	C3
6k.	Their aim is to conserve natural ecosystems	C4
6q.	Economic development is important for them	C5
6r.	Their engineering solution will drive the economy	
6n.	It is important for them to improve efficiency in engineering solution	C6
6i.	It is important for them to protect social rights	C7
6j.	Their engineering solution aims to contribute to human health	
6f.	Their aim is to contribute to an equal distribution of wealth	C8
6g.	They will value social equity in engineering solutions	
6h.	Their engineering solution aims at reducing gaps between generations	
6e.	They will take into consideration the needs of society/community	C9
6m.	They are responsible not only in the company but also outside the company	
6d.	Their engineering solution will meet the need of cultural diversity	C10
6c.	Stakeholders should be a part in developing their engineering solutions	C11
6a.	They should have full autonomy over decision making	C12
6b.	Ethics are important for them	
6u.	They will apply a holistic approach in decision making	C13
6v.	The balance of environmental, social and economic aspects is important for them	
6y.	Global security is a part of their responsibility	C14
6z.	They will take part in solving poverty.	
6w.	They will identify potential impacts of engineering to the local	C15
6x.	Local aspirations is important for them in engineering solutions	

The numerical values that are rated on the questions in this study were treated as scores. Similar to the analysis of conceptual maps and procedural diagrams, the total scores and the average scores were calculated for each of the categories. Table 4.12 demonstrates the process to analyze attitude towards sustainability.

Total score of $C_{i(i=1\text{-}15)}$ = Respondent 1´s score for C_i + Respondent 2´s score for C_i + Respondent 3´s score for C_i + Respondent 4´s score for C_i + Respondent 5´s score for C_i

The average score for each category can be formulated as follows:

$$MSi(Att) = \sum \text{Score of } C_{i\,(i=1\text{-}15)} / N$$

where;

$\sum$ Score of $C_{i\,(i=1\text{-}15)}$ is a total score for each of the categories

N is a total number of the respondents

Table 4.12 A sample analysis of questionnaires

Respondent	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Respondent 1															
Respondent 2															
Respondent 3															
Respondent 4															
Respondent 5															
Average of $C_{i\,(i=1\text{-}15)}$															
Samples N															
MSi(Att)															
Index of $C_{i\,(i=1\text{-}15)}$															

Later, the index value for each of the categories was calculated by averaging the chosen numerical values of the scale. The statistical formula for calculating the index value for the categories is as shown below:

$$\text{Index of Ci (Att)} = MSi(Att) / 5 \qquad \text{(Formula 7.3)}$$

where;

Ci is Category i (i = 1 to 15)

MSi(Att) is The Attitude Mean of Score for category i (i = 1 to 15)

5 is a constant value which are the maximum score for the scale

The index values can be interpreted in the continuum of agreement, which are valued from 0 until 1.00. The continuum of agreement is segregated into strongly disagree, disagree, neutral, agree and strongly agree. Table 4.13 can be a useful tool to understand the meaning behind the calculated index value.

Table 4.13 Level of agreement based on index value

Index value	Level of agreement
0.00 to 0.29	Strongly disagree
0.30 to 0.49	Disagree
0.50 to 0.69	Neutral
0.70 to 0.89	Agree
0.90 to 1.00	Strongly agree

4.5. Indicator of the course effectiveness

The indicator for learning sustainability in engineering education was uniquely designed to indicate three types of learning outcomes. In this case, the learning outcomes for learning sustainability are divided into knowledge, skills and attitude. It has to be unique because each of measurement tools produces different kind of data. The first measurement tool, the conceptual maps, aims to measure knowledge and produces data that identifies the elements of sustainability that are provided in the course and that are obtained by the students. The second measurement tool, the procedural diagram and self-rating procedure for measuring skills produces data that identify the level of skills provided in the course and that are acquired by the students. The third and last measurement tool, the attitude survey for measuring attitude, identifies the attitudes towards sustainability provided in the course and attained by the students.

The indicator for knowledge indicates the score that is expected by the teacher and the score (average) that is achieved by the students. The teacher´s score will always be indicated as 1 (the maximum index value); which means the score that students should achieve. Figure 4.8 illustrates an example of indicator for sustainability knowledge. The indicator has five important features. The indicator is graphically presented in a radar chart consisting of layers and categories. Each of the layers is valued with index values; the most outer layer is valued by 1 and the most inner (center point) is valued by 0.

Table 4.14 Indication of sustainability knowledge based on index value

Index value	Indication
1.0	All students were at least able to connect the category with the concept of sustainability
0.6 to 0.9	Majority of the students were at least able to connect the category with the concept of sustainability
0.5	Half of the students were unable to connect the category with the concept of sustainability
0.1 to 0.4	Majority of the students were unable to connect the category with the concept of sustainability
0	All students were unable to connect the category with the concept of sustainability

The labels on the most outer layer are coded with the fifteen categories of sustainability which are the same codes applied for analyzing data of the course evaluation. The example illustrates that the teacher´s score (in blue marks) are indicated in the radar chart as 1 for all categories. It indicates that the particular engineering course provides knowledge of sustainability which is including all the fifteen categories. It also indicates that it is expected that all students are able to obtain the knowledge (at least be able to connect the categories with the concept of Sustainability Technology). The red marks on the other hand, demonstrate the achievement of students to obtain the knowledge. For instances, the red marks show that the students obtains four out of fifteen categories. The categories are C1 with index value 0.2, C5 with index value 0.5, C9 with index value 1.0 and C12 with index value 0.8. As the red marks are positioned closer to the blue marks, this indicates that the students' achievement is closer to the teacher´s expectation and vice versa. The indicator for evaluating knowledge of sustainability can be comprehended by the following table:

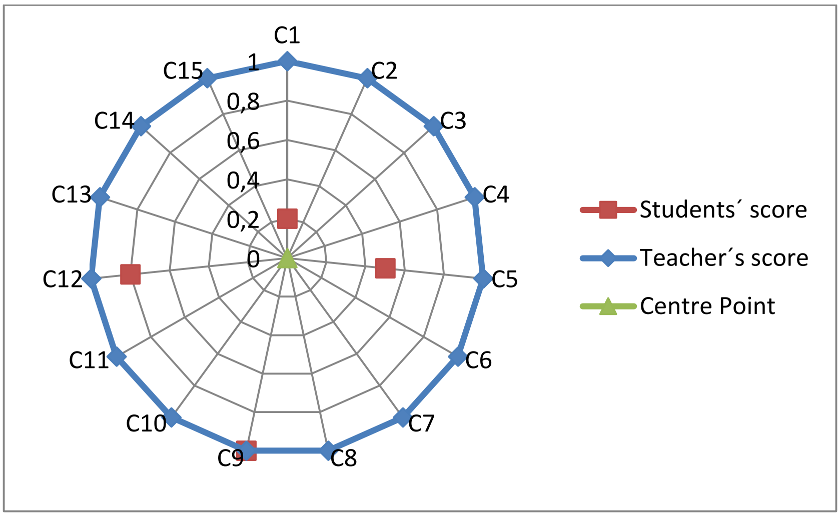


Figure 4.8 Example of indicator for Sustainability knowledge

The indicator for skills was applied to a radar map to graphically indicate the levels of sustainability. Figure 4.9 illustrates the level of skills provided in the course by referring to teacher´s scores (the blue markers). It depicts that the course provided skills up to skilled level (0.5 index value) for category C1 until C4 and C12 until C15, whereas the course provided skills up to master level for category C5 until C8. The figure also depicts the students´ scores (the red markers) for C1, C5, C9 and C12. It also depicts a basic level circle (the green circle) and a master level circle (the purple circle). The indicator shows that the students obtained skill for category C1 but marked inside the basic level circle which means that the students´ skill is in average and not passing the basic skill (the marker inside the green circle). On other hand, students in average achieved the expectation score for skill in category C9 (the students´ score is equal to the teacher´s score) and passed the basic level (the marker outside the green circle).

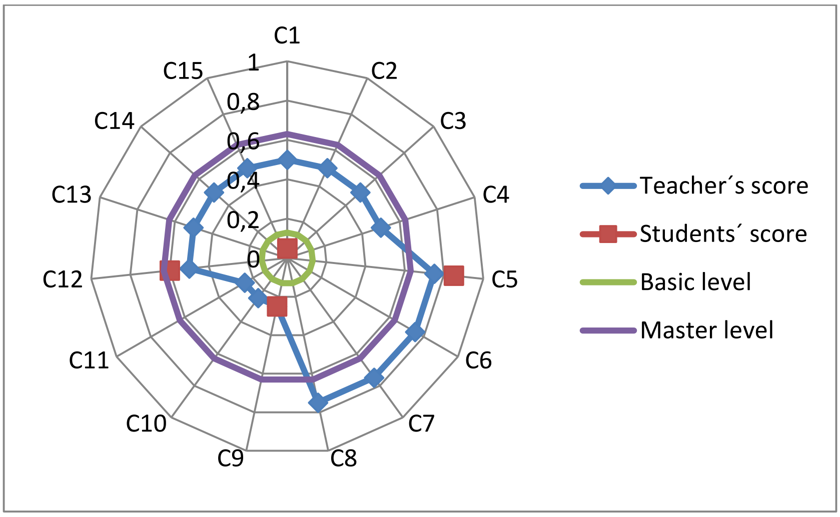


Figure 4.9 Example of indicator for Sustainability skills

When applying the radar chart as a graphical tool indicating sustainability attitude, the indicator consists of teacher´s scores (the blue markers), the students´ scores (the red markers) and consenting threshold (the green circle). Figure 4.10 illustrates the indicator for sustainability attitude. The indicator demonstrates that the engineering course results in a positive attitude towards sustainability for category C1 until C12, however, it has a negative attitude for category C13 until C15 based on the position of markers either inside or outside of the consenting circle. For instance, students´ attitude on economic category was perceived as a negative attitude since the students´ score for category C5 is marked inside the consenting threshold. Whereas the students´ attitude is perceived positive for citizenry (C9) as the marker for this category is positioned outside the consenting threshold.

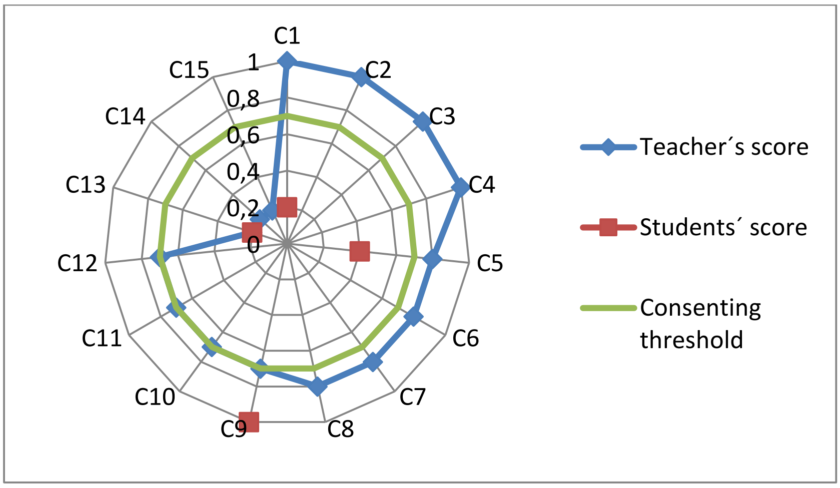


Figure 4.10 Example of indicator for sustainability attitude

4.6. Probing tool – questionnaires

There are two types of questionnaire that are potentially used as an approach to develop a probing tool which are close-ended questions and open-ended questions. Both types have their pros and contras in creating data (Fowler, 2009). In research phase three, a set of self-administered questionnaire was used to identify the factors that contribute to student´s learning outcomes in relation to learning sustainability. It was expected that the instrument will be distributed to all students who registered for the studied courses. Building on the role of teacher, role of student, role of learning environment, role of materials and role of the environments, a set of questionnaire consisting of 28 close-ended questions were constructed as a probing tool. According to Fowler (2009), in the (quantitative) survey research methods,

"Close-ended questions are usually a more satisfactory way of creating data. There are four reasons for this:

i) The respondent can perform more reliably the task of answering the question when response alternatives are given.

ii) *The researcher can perform more reliably the task of interpreting the meaning of answers when the alternatives are given to the respondents (Schumen and Presser, 1981)*

iii) *When a completely open-ended question is asked, many people give relatively rare answers that are not analytically useful. Providing respondents with a constrained number of answer options increases the likelihood that there will be enough people giving any particular answer to be analytically interesting.*

iv) *Since most data collection now is computer assisted, it is much easier for interviewers or respondents to record answers by checking a provided answer then to key in narrative answers*" [pp. 101]

The tool comprises an instruction for respondents, questions and a continuum. The questions are in such way that the respondents have to respond to each of the items by considering their current perspective on that particular course. The respondents have to mark on the provided agreement continuum on each of the statements which is the closest describing their actual perceptions. The continuum is ranging from strongly disagree to strongly agree (see Appendix B.7).

In the process of developing the probing tool, the research outcomes on the strategies of incorporating sustainability in engineering education from phase 2 were taken as essential inputs in knowing the variables that need to be measured. As a results of the analysis on the strategies, this study has focused on the five roles that represent several features of teaching strategies at both universities (UTM and AAU) such as problem based learning, project based learning, case based learning and industrial visits (see Table 4.15). Later in the process, the questionnaire has gone through a review process by peers and supervisors.

4.7. Analysis technique for the probing tool

The respondents´ feedbacks from the questionnaire have been clustered into five categories. The categories are i) role of teacher, ii) role of student, iii) role of learning environment, iv) role of learning materials and v) role of environment. Scores (from the scale) from each of the categories have been counted and averaged. The highest mean amongst the items in each of categories shows the significance of the variables to the factors that contribute to students' learning outcomes.

Table 4.15 Analysis of items

Teaching strategy	Category				
	Role of teacher	Role of student	Role of learning environment	Role of learning materials	Role of environment
Lecture	a	b w	d i	s z	l ac
Problem based learning	m u	c h n	p x	e r	f ab ac
Project based learning	m u	c o n v	j x y	e r	f t ab ac
Case based learning	a g	h o	x y	e k	l ab ac
Research based learning	u	c h	p	e r	t ac
A competition	m u	c h v	x	e r	t ab
An industrial visit	m	n w	d	r aa	f
A community service	g m	o	d y	e s	ab ac

Table 4.15 depicts the categorization of the items into the five roles in learning (horizontal) and teaching strategies (vertical). From the table, the researcher could identify what are the factors that contribute to students' learning outcomes by analyzing the data horizontally. Therefore, the mean value of each of the items can identify which variables contributed the most to the learning outcomes. For instance, if the mean value for item "o" was higher than the other items (b, c, h, n, v and w) in the same category, the researcher could make an assumption that one of the major factors in problem based learning (depends on the actual teaching strategy applied in that particular course) that contribute into learning outcomes is by participation of students in peer teachings.

4.8. The research instrument for phase 4

The main objective of data collection in phase four is to obtain teacher´s feedback on the proposed design framework. For that purpose, a 36-page document of the proposed framework has been distributed to the respondents for their reference during the process of evaluation. The proposed framework not only functioned as a guideline for course developer/designer but also has capability to be self-explained for the users. By this features, the users could employ the proposed framework to their engineering courses without any assistance from the framework developer.

There are potentially two aspects that can create a self-explained design framework which are the aspects of deliverability and practicality. The deliverability aspect is the capability of the framework to present ideas, models, strategies and approaches that are presented in the document. These include the structure of figures and the choice of colors. The framework also must have capability to provide understanding on the presented contents which includes sufficient information and should be well explained. In the aspect of practicality, the framework must have capability to engage the teacher by presenting the suitable strategies of sustainability incorporation in engineering education and align with the existing curriculum model. Therefore the presented strategies do not only theoretically works but are also applicable in practices.

Realizing the rich contents of the proposed framework, the attempt to develop a research instrument by employing self-administered close-ended questionnaires is very limited. This is due to the aims of the study that are not only to highlight the flaws of the framework but to be able to pin point which part of the framework requires further improvement. Therefore an open-ended questionnaire is the option.
According to Fowler (2009), he stated that:

> *"There are advantages to open-ended questions. They permit the researcher to obtain answers that were unanticipated. They also may describe more closely the real views of respondents" [pp. 101]*

Due to the homogeneity of the discussion topics, the open-ended questions were disseminated to the respondents in a focus group. In this research phase, the respondents have a group discussion in the form of two respondents, and later in a larger group (combining all groups). According to Freeman (2006),

> *"The main purpose of focus group research is to draw upon respondents´ beliefs, attitudes and feelings by exploiting group processes. There are many stated advantages to interaction between participants and, indeed, many see interaction as the key to the method. The idea is that group processes can help people to explore and clarify their views and attitudes efficiently, and encourages participation from those who feel little to say. The interpersonal communication between participants additionally helps to clarify similarities and differences in expressed opinions and/or values."* [493]

By these advantages, the researcher has constructed three sets of instructions underlining the aspects of deliverability and practicality.

The first set is:

In a group of two, discuss with your partner on deliverability of the framework. Deliverability could be the capability of the framework to:

a. Present the ideas/models/strategies

b. Provide understanding of the ideas/models/strategies

The second set is:

Discuss with your partner (in a group of 2?) on the practicality of the framework. Practicality could be the capability of the framework to:

a. Engage the teacher on the overall process

b. Apply to your own course

The third set is:

Discuss with your partner (in a group of 2?) on any aspects that need to be highlighted for improvement of the framework.

Analysis technique for phase four

Due to the approach for open-ended questions, the created data are expected to extremely vary. The data were not only acquired in written and oral forms but the data could possibly be in the form of illustrations and diagrams. Therefore, all type of data has to be transcribed and transform into a written form so that it can be further analyzed. The data for this research phase were analyzed into thematic analysis technique based on the two aspects of deliverability and practicality of the proposed framework. As a result, the data were categorized into four themes. The themes are:

i) The capability of the framework to present the ideas.
ii) The capability of the framework to provide understanding of the ideas.
iii) The capability of the framework to engage teachers in the design process
iv) The capability of the framework to apply to the existing courses

In the following table, this study provides several potential responses that could be acquired from the process of data collection. It is expected that the respondents for this research phase will give their feedbacks in a very open way and unorganized manner. Therefore, Table 4.16 can be used as a guideline to categorize the responses according to the analysis themes.

Table 4.16 Categorizing responses according to the analysis themes

Theme	Response that related to…
To present the ideas	i) Choice of figure ii) Choice of word font and size iii) Choice of color iv) Choice of configuration
To provide understanding of the ideas	i) Choice of word ii) Overelaborate or under elaborate iii) Create confusion in terms of meaning iv) Contradict statements v) Unclear explanation
To engage teachers in design process	i) The process of incorporation ii) The process of design iii) Insufficient information on curriculum design process iv) Insufficient information on the concept of sustainability
To apply to the existing course	i) Alignment of the proposed framework and the existing curriculum model

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Chapter 5

Phase one: Exploring real world practices

5.1 Introduction

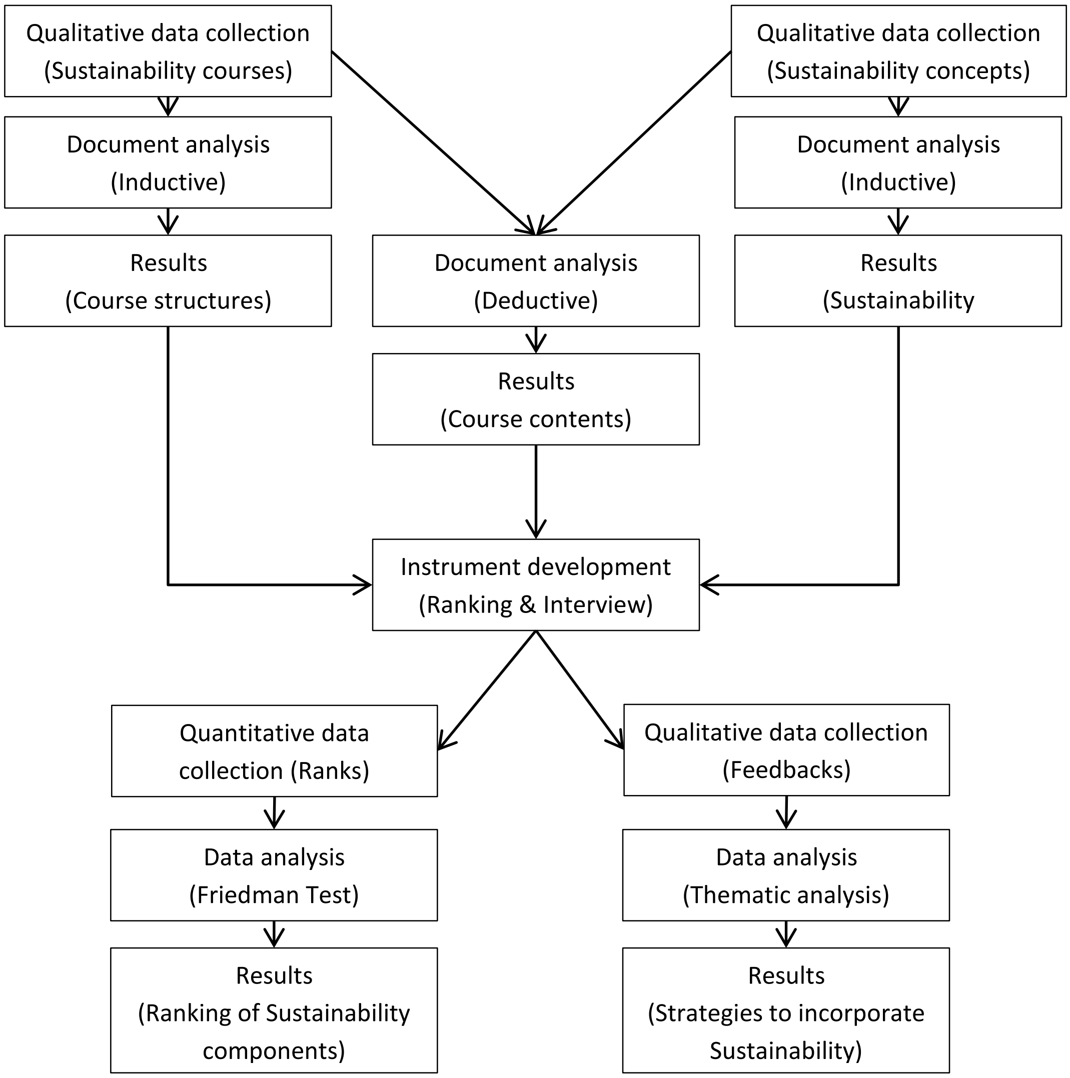

Figure 5.1 The presentation paths for phase one

This chapter presents the state of the art of sustainability in engineering education by exploring practices around the world. The presented cases are based on the results from qualitative data analyses (on sustainability concepts, principles, and sustainability courses), development of research instruments (ranking instrument and interview questionnaires), and data analyses of expert feedback. Figure 5.1 shows the paths of the presentations. The figure also shows how the results from the state of the art of sustainability in engineering education are used to develop the research instruments for this phase.

5.2 Inductive analysis on sustainability courses

The analysis of the selected courses is based on the basic structure of sustainability course models, stand-alone models and integrated models. The analysis also includes other components that are important for designing sustainability course such as learning objectives, course contents, assessment methods, teaching strategies and important remarks made by authors and teachers. Even though there are some basic components for the analysis, the sustainability courses were analyzed on their similarities and common practices in structuring sustainability course. This could permit the researcher to apply inductive analytical techniques in order to understand not only the common practices but also to identify other possible methods taken by the universities to incorporate sustainability into the existing engineering curricula. As a result of the analysis, other than the two models of sustainability course (as one dimension), the sustainability courses also include a different dimension of course structure. This dimension is identified as disciplinary and interdisciplinary orientations. Later, the selected sustainability courses were categorized into models and orientations as depicted in the following table.

Table 5.1 Analysis of sustainability course

No	Title of Course/Article	Models		Orientations	
		SAM	IM	DO	IO
1	Sustainable design and construction		Y	Y	
2	Sustainable civil infrastructure systems		Y	Y	
3	Design 5		Y	Y	
4	Applied Sustainability and Public Health in CE Design		Y	Y	
5	Ecological Engineering 2		Y	Y	
6	Business, Society and Environment	Y		Y	
7	Sustainable development and responsibility	Y			Y
8	Environmental Principles for Sustainable Design	Y		Y	
9	Education and Awareness for Sustainability	Y			
10	A Sustainable Development Course for Environmental Engineers in Kyrgyzstan	Y		Y	
11	Engineering Clinic	Y			Y
12	Introduction to Engineering Practice	Y		Y	
13	Engineering Analysis and Problem Solving	Y			Y
14	Climate, Sustainability and Society	Y			Y
15	Materials and Resources	Y			
16	Moral and Ethics in Engineering Profession		Y		Y
17	Environmental Challenges and Leadership in Asia	Y			Y
18	Sustainable Process Development		Y	Y	
19	EEWS Technology and Commercialization Perspectives	Y		Y	
20	Environmental Studies	Y		Y	

21	Ubiquitous Sustainable Engineering		Y	Y	
22	Engineering for Sustainable Built Environment	Y			Y
23	Sustainability Technology Evaluation and Theory	Y			Y
24	Global Threats and Sustainability	Y			Y
25	Understanding Environment, Development and Sustainability	Y			Y
26	Ecological Engineering Practices		Y	Y	

5.3 Results and discussions - Course structures to incorporate sustainability in engineering curricula

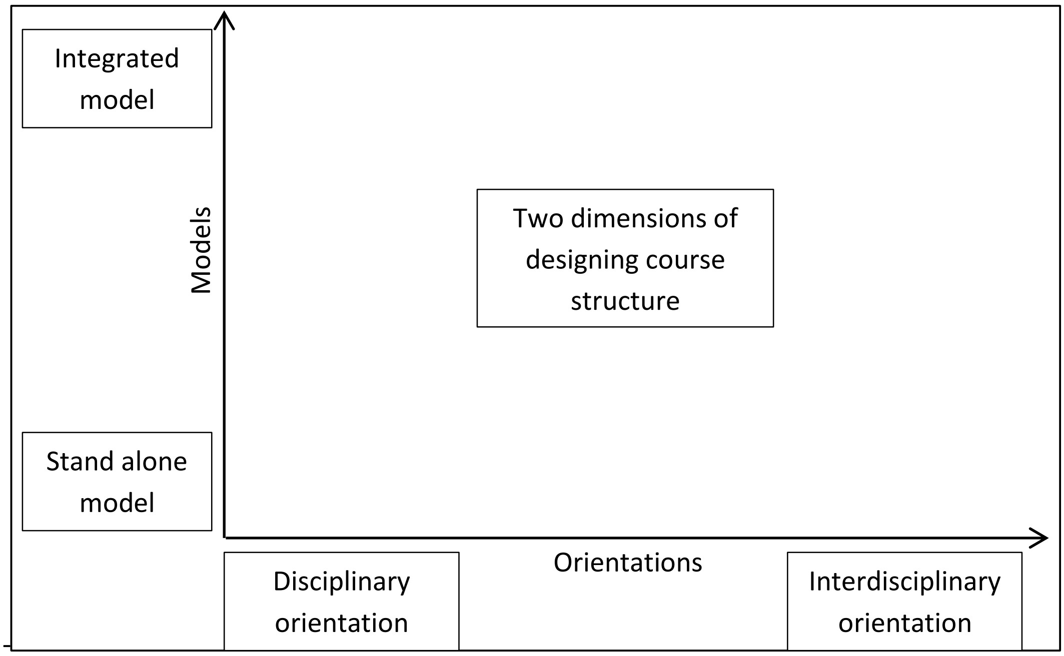

Figure 5.2 Two dimensions of course structure

Results from the analysis (mostly from the provided learning objectives and course contents as well as the strategies taken for the implementation), it is worth highlighting that in practice sustainability courses have been structured by two dimensions. First, the courses are structured by following two models, stand-alone model and integrated model. Second, the courses are also structured by considering two types of orientation, disciplinary orientation and interdisciplinary orientation. Both model and orientation exist in every sustainability courses because they offer different purposes.

Models

The first dimension in structuring sustainability course in engineering curricula consists of the two basic models. The two basic models proposed in this chapter are the stand-alone model and the integrated model. The models have been further developed by taking analyses of six cases of Kitamura and Hoshii (2006), Salih (2008), Holmberg (2008), Coral (2009), Murphy (2009) and Chhokar (2010) as the point of departure.

Table 5.2 Basic structures of sustainability course

Study	Course structure	
	Stand-alone model	Integrated model
Kitamura and Hoshii (2006)	Newly formulated or existing course as a minor course	Part of the existing course
Salih (2008)	Stand-alone subject model	Embedded model
Holmberg (2008)	New minor course	
Coral (2009)	Compulsory course	Integrated in final year project
	Minor course	Intertwined in all courses
Murphy (2009)	Dedicated SD course	Integrated as topic
Chhokar (2010)		Integrated modules/courses

Stand-alone model

Generally, this model is applied at an early stage of curriculum transformation where a university introduces sustainability courses either incorporated or separately into the programs. The stand-alone model means that a new course will be designed and constructed to provide understanding of sustainability with no intention to incorporate the knowledge (or other competencies) into the existing engineering courses. The advantage of this characteristic is that it is believed that the course can be applied to other programs and faculties without much adaptation. Figure 5.3 illustrates a stand-alone model that is applied to a sustainability course for Program 1 and Program 2.

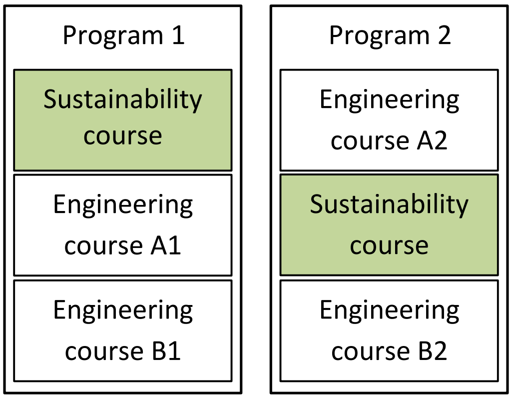

Figure 5.3 Stand-alone model: A sustainability course is introduced to both programs

For example, a course entitled “Climate, Sustainability and Society” shows that its learning objectives and course contents can be characterized as stand-alone model. This course has stated six learning objectives. Two of the learning objectives are visibly related to sustainability (Russell, Legge and Petrolito, 2009):

i) Develop a vocabulary of contemporary definitions and theories related to climate, sustainability and society.

ii) Recognize and use the semantic base from each of science, social science and economics.

The course has introduced the concept of climate and climate change, confronted with the impact of society on the environment and the changing environment on society, exposed to three high-profile public speakers, and debate and appreciate the complexity of sustainability issues (Russell, Legge and Petrolito, 2009).

Another course of the same kind is offered at Middle East Technical University, Turkey. This course called `Education and Awareness for Sustainability´ aims to help students to understand how the environment can be improved by adapting their daily life and work (Erdogan and Tuncer, 2009). Students will also actively participate on activities related to sustainable development in which social values, feeling of concern to environment and motivation are acquired. The course incorporates engineering, technology, health and science together with sociology, geography, history, management, literature and mathematics. All these components are blended in lectures as well as in students´ activities such as discussions, brain storming and field trips (Erdogan and Tuncer, 2009).

Both courses mentioned above are purposely constructed to introduce the sustainability concept in engineering education and intentionally designed not to be incorporated into existing courses. With respect to the learning outcomes, the sustainability courses are designed for a general course, not aiming at specifics programs. Although both courses are characterized by the same basic model, the differences between both courses show how the sustainability concept can be developed in various ways. The first example shows that the sustainability concept can be developed by lecturing and debating the general issues of sustainability, while the second example shows that team working and field trips are used to put the sustainability concept to practice.

Integrated model

Conceptually, the integrated model is a model where sustainability components are integrated into regular or traditional engineering courses. This model requires course designers to revise and reconstruct engineering courses and adapt the sustainability concept to the needs of the curriculum. Therefore, the sustainability concept will not only be introduced to engineering fields but it will purposely be designed to the application, evaluation and synthesis levels.

Boks and Carel Diehl (2006) give an example of integration of sustainability in an existing engineering course. The course, labeled Design 5, has been offered at industrial design engineering at Delft University of Technology, Netherlands for final year bachelor students. Design 5 is planned to encourage students to apply theories of `Product Development in Industrial Context´ and `Market and Consumer´ as well as integrate sustainability into product design (Boks and Carel Diehl, 2006).

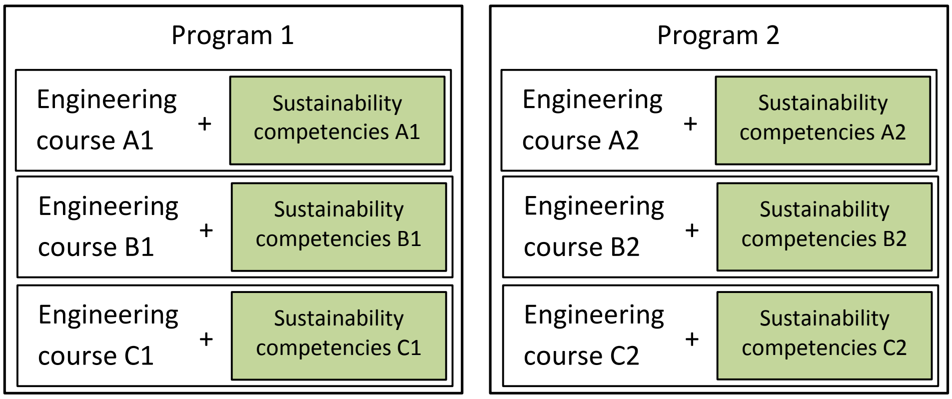

Figure 5.4 Integrated model: Sustainability is incorporated into regular courses

Another example of an engineering course that is characterized by the integrated model is `Applied Sustainability and Public Health in Civil Engineering´. This course is offered to civil engineering students at Queen´s University, Canada. The main objectives of the course are to evaluate global environment impact and public local impact of civil engineering design work as well as to apply concept and methods in Life-cycle Assessment (LCA), Economic Input-Output (EIO) analysis and Quantitative Risk Analysis (QRA) (Filion, 2010).

Both examples show how sustainability components have been incorporated into the body of existing courses. The integrations can be realized on the sustainability components, such as impact of environment and social skills, which cross over the engineering curricula. However the idea of integrating sustainability in every course depends on the question of how much sustainability components can be incorporated into the existing courses. Sustainability is not a component in the final steps of engineering design, such as calculation of CO2 emissions. It is about a complete cycle of design, from the sketch until the real products.

Orientations

Orientations are the second dimension that can be used to construct sustainability course in engineering curricula. This dimension focuses on how learning objectives are formulated and how the choice of content is made from the pool of discipline knowledge. By contrast, the first dimension concentrates on the question of how sustainability can be constructed and incorporated into an existing program.

Disciplinary orientation

Disciplinary orientation can be described as a traditional method of subject teaching. The disciplinary orientation only focuses to provide learner with specialized skills and concepts in a field without any intention for integration (Jacobs, 1989). Figure 5.5 shows sustainability courses that are constructed to fit within specific disciplines or a particular program. Normally, the programs offered at university are discipline oriented and the courses have been constructed to be relevant and to satisfy the program's learning objectives. In the field of engineering, most universities have divided engineering disciplines into several programs such as mechanical engineering, electrical engineering, chemical engineering and civil engineering. Two sustainability courses that can be characterized as discipline oriented will be further explained.

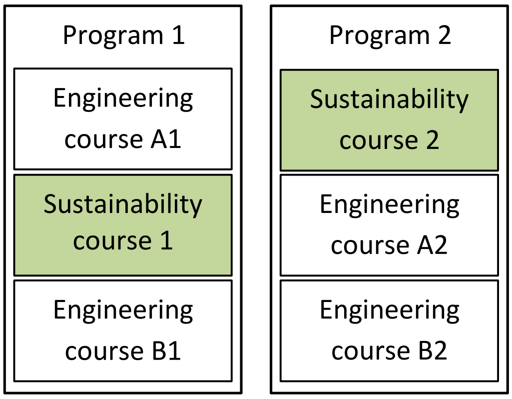

Figure 5.5 Disciplinary orientation: Sustainability courses are contextualized into the disciplines

In 2004, Arabaev Kyrgyz State Pedagogical University started to offer sustainability course for ecological engineering students and decision makers. The course mainly focuses on Central Asian ethnic problems, like nature conservation and nature exploitation activities. Issues of sustainability have been incorporated into ecological and eco-technology such as hydroelectric stations, bio-gas machine, sun collectors for water boiling and room heating, and sun-drying equipment for crops and vegetables. As an addition, the course developer includes emotional form using poetry and religion in the context of ecology (Hadjemberdiev, 2004).

Another example has been described in a research article in 2010 by Gardiner (2010). He presents a sustainability course that was offered to Industrial Engineering, and Information and System Engineering students. Basically, the course has been designed to introduce concepts, methods and principles of engineering practice, problem solving, design, project planning, communication, team work, ethics and professionalism, innovative solution development and implementation. Several learning activities such as group work and forum discussions have been introduced to attain the learning objectives and suitable platforms have been provided for students to carry out research on topics related to sustainable development (managing Nitrogen Cycle, clean water, feeding the world, poverty, climate and hunger, solar system and etc.).

Based on these two articles, the concept of sustainability has been introduced and developed based on the particular perspective of one discipline. Without cross-disciplinary content, the concept of sustainability has intentionally been focused on one engineering discipline emphasizing how an engineer in this discipline reflects on issues of sustainability. The articles show that the learning objectives and course contents have been narrowed down to ecological and industrial-system engineering disciplines without sacrificing any pillar of sustainability. However, it should be noted that the practices to put the general concept of sustainability into a corner of one specific discipline is at odds with the interdisciplinary characteristic of sustainability concept itself.

Interdisciplinary orientation

In contradiction to the disciplinary orientation, the interdisciplinary orientation “purposely brings together the full range of disciplines in the curriculum and uses a full array of discipline-based perspectives” (Jacobs, 1989). The impact of a course with interdisciplinary orientation depends on the range between one disciplinary and other disciplines. A sustainability course that caters all four conventional engineering disciplines, mechanical, electrical, chemical and civil disciplines, has to deliver and satisfy all program learning objectives. Unlike combining two or three disciplines in the same pool of knowledge, constructing sustainability courses for a wide range of disciplines demand strong corporation and agreement on selecting learning objectives as well as course contents.

Figure 5.6 illustrates that the position of a sustainability course is bridged from Program 1 to Program 2. The course can be single sustainability course or more, but implementation of the course(s) has to cross disciplines and no changing or rearranging of learning objectives is required according to specific discipline. Hollar and Sukumaran (2002) give an example of an interdisciplinary oriented sustainability course. The course has been offered to all engineering disciplines students at Rowan University. The learning objectives have been designed to meet the needs of workplaces such as technical knowledge, communication skills, and awareness of social implication, lifelong learning ability and ethical judgments. The learning objectives are:

i) Calculate greenhouse gas emissions for university.

ii) Propose low-cost solutions to improve energy efficiency.

iii) Propose alternative energy sources that can be incorporated into the future growth.

iv) Perform economic analysis (short term & long term).

v) Formulate a well-supported, articulate oral argument for using alternative energy sources.

This course has been prepared for engineering students to acquire the knowledge of sustainability by practicing real world problems, experiencing authentic engineering design project, such as designing a sustainable energy, and applying knowledge of economic.

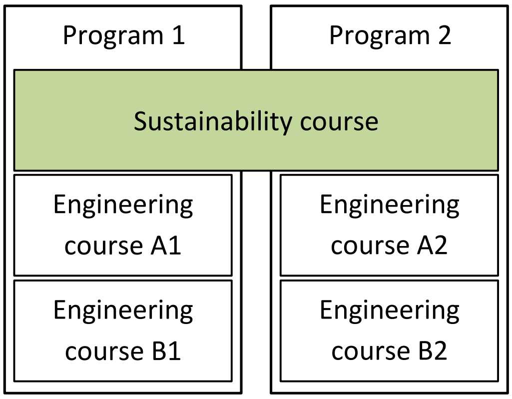

Figure 5.6 Interdisciplinary orientation: A sustainability course is purposely designed for two programs (disciplines) or more

Another example of an interdisciplinary oriented course is presented by Kemppainen, Veurink and Hein (2007). Three objectives were formulated for this sustainability course.

- The first objective is an introduction to the engineering profession and to its various disciplines.
- The second objective is that the student will focus on developing problem solving skills, computational skills and communication skills.

- For the third objective, student will apply engineering problem solving method to real world problems.

Case study and problem solving methods are instructional strategies used to cover general engineering topics and concept of sustainability. The course designer has also applied engineering achievements, ethics case studies, globalization and individual lifestyles as four frameworks to build up knowledge and skills of sustainability.

The interdisciplinary oriented courses presented above have shown that the course orientation can be attuned to the interdisciplinary nature of the sustainability concept. The learning objectives and course contents are achievable and suitable for a wide range of disciplines. However, mutual consensus has to be reached, to avoid imbalanced and unsynchronized course learning objectives with the program learning outcomes.

5.4 Analysis on concepts and principles of sustainability

The analysis on the concepts and principles of sustainability has been carried out from the collections of several studies and online documents (noted in Table 5.3 as A, B, C and so on). An inductive analytical technique was applied in the analysis process where the themes emerged from the common issues of sustainability discussed in the studies and documents. Later, the common issues of sustainability (usually very details) were clustered under categories that are represented by components of sustainability that are general in its characteristic and link several issues of sustainability. As a result of the analysis, there are many common issues of sustainability discussed in the studies. The common issues can be categorized into 16 components of sustainability which are:

1) **Fundamental concepts of sustainability**
2) **Empowerment of engineer**
3) **Environmental management**
4) **Environmental assessments**
5) Preservation of **resources**
6) **Social rights** and social values
7) Concern on **citizenry** issues
8) **Equity** of inter-generation and intra-generation
9) Preserve **culture**
10) **Quality in engineering**
11) **Green or Eco technology**
12) **Holistic approach/ integrative approach**
13) **Stakeholders**
14) Concern on **global** issues
15) Concern on **local** issues
16) Development of **economy**

Table 5.3 Analysis of the concepts and principles of sustainability

Concepts	SD	SD	SD in engineering	SD in engineering	SD in engineering	SD in engineering	SD in engineering	SD in engineering education	SD in engineering education	SD in engineering education	SD in engineering education	**No of documents/studies**
Author(s)	A	B	C	D	E	F	G	H	I	J	K	
Components of sustainable development from the concepts and principles												
Fundamental concepts of sustainability							**	*		*	*	4
Empowerment of engineer and Ethics/moral	*	**	**		*		*	*		*	*	8
Environmental management			*	*	**	*	*	*	**			7
Environmental assessments		*	*	**			*		*	*		6
Resources	*	*		***	**	**		*				6
Social rights/value		**		*	**		**	**		*	***	7
Citizenry			*					*	*			3
Equity	*	*	*		**	*						5
Culture		*	*	*			*	*			**	6
Quality in engineering						*	*			*		3
Green or ecology technology	*		**				**			*		4
Holistic approach/integrative approach	*	*	*	*	**	*		*	****	*		9
Stakeholders				*			*	*	**	*		5
Global	*						*	*				3
Local				*				*	*			3
Economic					*							1

"*" indicates number of documents/studies

5.5 Results and discussions - Components of sustainability in engineering

The attributes of engineer in acquiring the fundamental concepts of sustainability can be seen in the Declaration of Barcelona where engineering students are expected to *"participate actively in the discussion and definition of economic, social and technological policies…"* (Barcelona Declaration, 2004). The basic concepts of sustainability, such as the concepts of social, cultural and environmental should be understood precisely, so that engineers not only use their technical training solely as a way of creating solutions but also will be able to provide sustainable solutions rather than traditional technical solutions (Taoussanidis and Antoniadou, 2006). The engineering students are also expected to *"understand the impact of professional engineering solutions in societal and environmental context and demonstrate knowledge of and need for sustainable development"* (International Engineering Alliances, 2009).

A study by Jabareen (2004) showed that SD has been developed around ethical concerns, which are, in this context suitable to be incorporated in engineering profession. The ethical concerns in SD were debated to the extent that, *"Individual wants (preferences) have to be distinguished from needs. For humanistic and institutional economists, individuals do not face choices over a flat plane of substitutable wants, but a hierarchy need…. Sustainability imperatives, therefore, represent high-order needs and values,"* (Turner, 2005). This attribute, the engineering ethics, has been discussed in various studies where ethical concerns are highlighted as a crucial attribute for engineering profession in achieving sustainability. As the discussions on the importance of ethical concerns in SD continues, abilities to apply ethical principles and to commit to the engineering ethics are stated as the attributes for professional engineers in the international engineering alliances in 2009 and outlined in Barcelona Declaration earlier in 2004.

In our findings, sustainability has to be framed into local context; which is in line with one of the principles of green engineering, results from the Sandestin Conference in 2003, *"Develop and apply engineering solutions, while being cognizant of local geography,…"* (Abraham and Nguyen, 2003). The relationship of SD and global issues is very significant, where many issues such as security, peace and trade, hunger, shelter and water are discussed internationally (Jabareen, 2004). The engineers are expected to *"understand how their work interacts with…local and globally, in identifying potential challenges, risks and impact"* (Barcelona Declaration, 2004) as well as to *"identify potential impacts of their proposed actions, not only locally but also outside their immediate local environment organization and context and future"* (Dodds and Venables, 2005).

The approach in dealing with engineering problems or issues in any levels of engineering processes for sustainability is significantly pointed to holistic approach or integrative approach, and could also be called a systemic approach. In this chapter, the holistic approach can be divided into two contexts; the first context concerns more on the planning and management for SD, where Jabareen (2004) in his study had related SD with the integrative management metaphor. *"This metaphor represents the sustainable development´s integrative view of the aspects of social development, economic growth and environmental protection. It is believed that in order to achieve sustainability and ecological integrity,… we need an integrative and holistic management approach"* . The second context however concerns more on the process of solving problems and manifesting the solutions. Boyle and Coates (2005) outlined pragmatic ways of solving problems holistically for engineer by creating *"solutions based primarily on human needs and ecosystem viability rather than the availability of technology or technological method"* and they added *"an integrated systems, or an overall holistic, approach shall be taken including all stakeholders and the environment when attempting to solve problems. Rather than focusing solely on the technology aspects, and solving one problem at the expense of another,…"*.

"Engineers have traditionally seen themselves serving clients: their clients or employers; society at large; and their profession. If engineers can truly integrate principles of sustainable development into their designs as well as their attitudes, they can actually fulfill their duties to all these parties concerned." (Manion, 2002)

The need of holistic approach is further reasoned by Fenner et al. (2004), he stated that *"no single act of development can achieve its objectives in complete isolation from all other aspects. A systemic approach is required…..problems are not dealt with an isolation but solutions are conceived against a wider understanding of the overall system response. Thus the provision of an engineered artifact or service is not divorced from the needs of its end user community. Neither are its whole life impacts ignored during the separate phases of design, implementation, operation and disposal".*

Some of the studies propagated the holistic approach into the approach called \`cradle-to-grave´. The approach emphasizes on the effect on sustainability throughout the whole life-cycle of a product. The effects should be evaluated from the \`cradle´, decision making, designing, and producing, up to the \`grave´, the materials are adaptable for recycling or re-use and avoidable from disposal problems (Dodds and Venables 2005).

The concept of green or ecology technology was clearly defined by Jabareen (2004) with his Eco-form metaphor. The metaphor, as he stated, *"represents the ecologically desired form of urban spaces and other human habitats. A key strand of research into sustainability strategies has focused on ecological design …. Sustainable design aims to create eco-forms, which are energy efficient and designed for long life"* (Jabareen, 2004). *"To incorporate a temporal context into design requires…some understanding of sustainable technologies and processes, as developed today, needs to be included"*(Taoussanidis, and Antoniadou, 2006). The importance of the concept of green or ecology technology is further explained as a part of green engineering; *"…engineers will be upholding the ideals of their profession. ....by following green engineering, they will be fulfilling their obligations to self in that each individual engineer can be proud of that they are doing by society and the environment"* (Manion, 2002).

Environmental issues are the origins of the concept of SD. The knowledge of environmental management *i.e.* waste and water management always has been included in many debates either in the principles perspective or pragmatic point of views. Environment and environment management must be valued together with economic development (Manion, 2002). Engineers must strive to prevent waste (Abraham and Nguyen, 2003), improve the quality of the environment by maximizing the use of alternative materials and at the same time minimize waste (Fenner et al, 2004).

For Boyle and Coates (2005), engineers have to be firm in dealing with environmental issues. They suggested that engineers have to *"eliminate all waste products, minimize or eliminate the use of hazardous material and reduce the use of materials and chemical that can accumulate in the environment".* Besides the knowledge of environmental management, issues related to the resources and eco-systems are also in the heart of sustainability debates. The resources and eco-systems, also known as natural capital (Fenner *et al.* 2004; Jabareen, 2004), is not the only driver of sustainability but it also includes other components of sustainability (Fenner *et al.* 2004). Constantly natural capital and environmental issues are referred to the criteria in sustainability either in engineering practices or in engineering education.

The acceptance of social values in SD in the level of principles and concepts is always sufficiently discussed and represented. All the principles, based on Table 1, include the components of social rights/value, social equity, culture and citizenry as criterion to achieve sustainability. The issues evolved in social rights/values encompass protection of human health and well-being (Abraham and Nguyen, 2003), public participation and involvement in engineering decisions (Fenner *et al.* 2004), relationships with technologies (Bell, 2011), social safety and legal (International Engineering Alliances, 2009), and the interaction of engineers with society (Barcelona Declaration, 2004). Therefore, *"the education that engineers will obtain through sustainability engineering will provide them with a better understanding of systems and processes and the roles of business and government in society" (*Taoussanidis and Antoniadou, 2006).

In the discourse on social equity, the social equity not only responses to the fairness between different groups, nations or geographical differences, it incorporates the equity between the current generations and the future, the rich and the poor. In referring to the fairness metaphor by Jabareen (2004), the metaphor generally strives for fairness in resources allocation among different groups such as *"ethnic group, present and future generations, northern and southern countries and developed and developing countries*". The intragenerational and intergenerational equity concept by Turner (2005) in addition, is in the same idea of Jabareen (2004), where the *"future generations have the right to expect an inheritance sufficient to allow them the capacity to generate themselves a level of welfare no less than that enjoyed by the current generation"* (Turner, 2005). It is necessary for engineers to value the *"future as well as the current generations"* (Manion, 2002), whereby in valuing the social equity, Boyle and Coates (2005) suggested that there should be equal opportunities for every affected people on engineering projects. They added, to achieve sustainability, every generation has "*equal right to achieve an acceptable quality of life"* by reducing gaps between generations, "*reducing excessive consumption of resources by the wealthy"* and filling the poor.

Engagement of stakeholders in engineering processes will give different views, perceptions, knowledge and skills (Dodds and Venables, 2005). Engineers have to actively engage with stakeholders as well as communities (which are part of stakeholders) in developing engineering solutions (Abraham and Nguyen, 2003). Findings from interview session with teacher show that it is important for engineers to satisfy the needs and criteria set by stakeholders. In fact, from the finding, most stakeholders nowadays have shown their commitments and they have driven the implementation of sustainability in work places but not in the context of engineering education.

The finding also has been highlighted back then in 2006, where the study stated that, *"…engineers remain ill-prepared to take on "extra-mural" responsibility - that is, responsibility in relation to key stakeholders in the wider society or the firm´s geographical context"* (Taoussanidis and Antoniadou, 2006). Therefore for future improvement, it is suggested to incorporate and create a space for students to acquire this attribute; the attribute for future engineers to *"listen closely to the demands of citizens and other stakeholders and let them have a say in the development of new technologies and infrastructures"* (Barcelona Declaration, 2004), *"…to reflect on the stakeholders and values involved in their work, including identifying key tradeoffs between competing values."* (Bell, 2011)

Environmental assessments are acceptably having a strong relationship with environmental management and constantly relate to the technical part of sustainability, where tools and instruments are applied to assess the impact of engineering technology towards the environment. These assessments *i.e.* environmental impact assessment, life-cycle analysis, risk assessment need to be trained to engineers and these assessments part need to be considered as a part of engineering design (Taoussanidis and Antoniadou, 2006). The engineers are also suggested to *"….use system analysis, and integrate environmental impact assessment tools"* and *"use life cycle thinking in all engineering activities"* (Abraham and Nguyen, 2003).

Assessing the environment also becomes more important when it is assessed and translated into monetary-value, this is defined by Dodds and Venables (2005), as a cost or compensation charge. The importance of assessing environment was further explained as stated, *"there is an essential link between sustainable development and monetary valuations of the environment in terms of willingness to pay (WTP)"* (Turner, 2005).*"For some years now, engineering curricula have been increasingly taking into account the "intra-mural" responsibility of the firm, which involves issues of quality, hygiene, safety, …."* (Taoussanidis and Antoniadou, 2006). This 'intramural' responsibility is apparently related to the quality in engineering creation, where issues of hygiene and safety are combined as well as product efficiency, wide scales technologies and systems. The quality of engineering creation continues to be part of engineering responsibility, and we perceived it as a part of SD.

Table 5.4 Components of sustainability

<table>
<tr><th colspan="3">Sustainability pillars</th><th>Sustainability Components</th></tr>
<tr><td rowspan="4">Environment</td><td rowspan="3"></td><td rowspan="5"></td><td>Environmental management</td></tr>
<tr><td>Environmental assessments</td></tr>
<tr><td>Resources</td></tr>
<tr><td rowspan="6">Economic</td><td>Green/Eco technology</td></tr>
<tr><td rowspan="8"></td><td>Economic
(Profits)</td></tr>
<tr><td rowspan="11">Social</td><td>Quality in Engineering</td></tr>
<tr><td>Stakeholders</td></tr>
<tr><td>Social rights/value</td></tr>
<tr><td>Equity</td></tr>
<tr><td rowspan="3"></td><td>Citizenry</td></tr>
<tr><td>Culture</td></tr>
<tr><td>Empowerment of engineer and ethics/moral</td></tr>
<tr><td rowspan="4"></td><td rowspan="4"></td><td>Fundamental concepts of sustainability</td></tr>
<tr><td>Holistic app/systemic app</td></tr>
<tr><td>Global issues</td></tr>
<tr><td>Local issues</td></tr>
</table>

5.6 Analysis for course content

Table 5.5 Components of sustainability offered in 26 engineering courses

	Components of sustainability in engineering															
	Fundamental knowledge of sustainability	Empowerment of engineer and Ethics/moral	Environmental management	Environmental assessments	Resources	Social rights/value	Citizenry	Equity	Culture	Quality in engineering	Green or ecology technology	Holistic approach/ integrative approach	Stakeholders	Global	Local	Economic
No of courses (/26)	13	9	5	9	5	7	1	0	0	3	8	4	1	7	8	6

In order to analyze the course content offered by the 26 engineering courses, the learning objectives and the topics offered become the dominant references. The analysis of course content provides understanding on how is sustainability contextualized into the engineering disciplines. A deductive analytical technique was applied to categorize the learning objectives and the topics of the engineering courses into sixteen components of sustainability which are presented earlier. Table 5.5 shows the result from the deductive analysis of 26 engineering courses that are related to sustainability. Table 5.6 on the other hand depicts the result by categorizing each of the engineering courses into three approaches. They are approaches to contextualize sustainability into engineering disciplines. The approaches are singular approach, dialectic approach and consensual approach.

Table 5.6 Categorization of 26 engineering courses into three types of approach

No	Title of Course/Article	Approaches		
		S	D	C
1	Sustainable design and construction		Y	
2	Sustainable civil infrastructure systems			Y
3	Design 5	Y		
4	Applied Sustainability and Public Health in CE Design		Y	
5	Ecological Engineering 2		Y	
6	Business, Society and Environment			Y
7	Sustainable development and responsibility			Y
8	Environmental Principles for Sustainable Design	Y		
9	Education and Awareness for Sustainability		Y	
10	A Sustainable Development Course for Environmental Engineers in Kyrgyzstan			Y
11	Engineering Clinic		Y	
12	Introduction to Engineering Practice	Y		
13	Engineering Analysis and Problem Solving			Y
14	Climate, Sustainability and Society			Y
15	Materials and Resources			
16	Moral and Ethics in Engineering Profession			Y
17	Environmental Challenges and Leadership in Asia	Y		
18	Sustainable Process Development			Y
19	EEWS Technology and Commercialization Perspectives		Y	
20	Environmental Studies		Y	
21	Ubiquitous Sustainable Engineering	Y		
22	Engineering for Sustainable Built Environment	Y		
23	Sustainability Technology Evaluation and Theory			Y
24	Global Threats and Sustainability		Y	
25	Understanding Environment, Development and Sustainability			Y
26	Ecological Engineering Practices		Y	

In addition, the outcomes of the analysis also provide an understanding on the contextualization of sustainability corresponding to the levels of learning (Bloom´s taxonomy as a reference). It is a strategy to design course content related to sustainability that is compatible with the existing level of learning (*i.e.* application level). The strategy can be represented by four themes.

5.7 Results and discussions - Course contents of sustainability in engineering curricula

From both analyses, there are two dimensions of designing courses which are approaches dimension and themes dimension. In approaches axis, sustainability knowledge can be incorporated into the course content by applying singular, dialectic or consensual approaches. Meanwhile, in themes axis, sustainability knowledge can be designed either by connecting sustainability to the engineering profession or by conceptualizing sustainability into the engineering design or by valuing sustainability in the engineering justification or implementing sustainability into the engineering solutions.

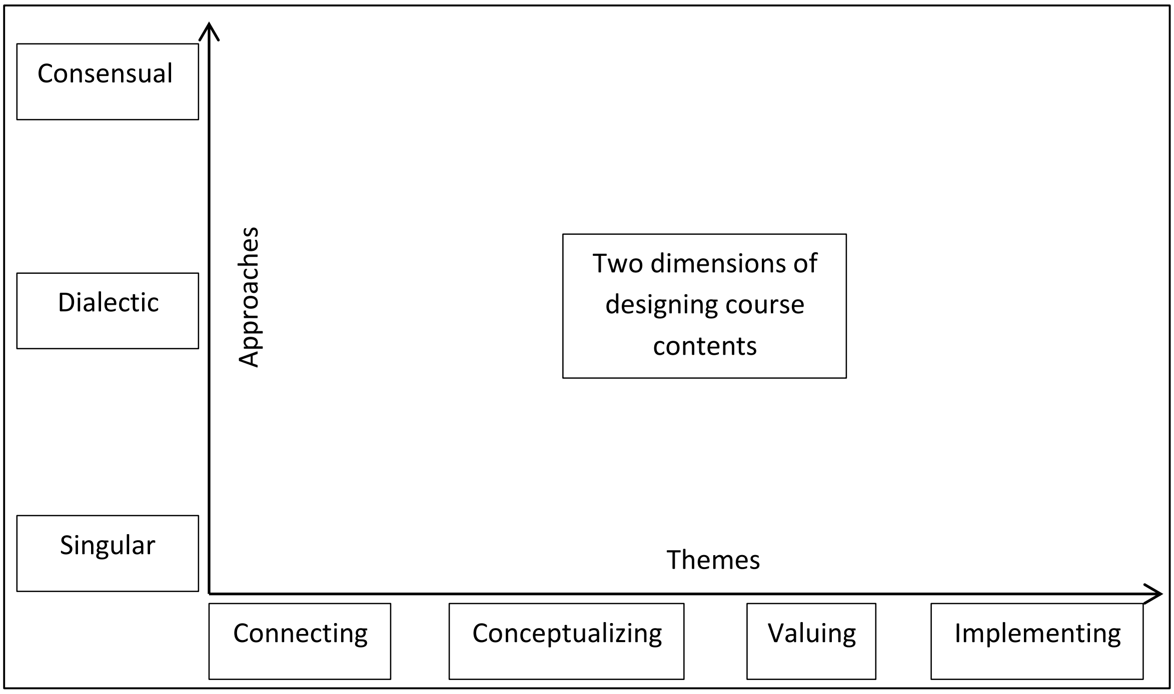

Figure 5.7 Two dimensions of designing course contents

Approaches

The three pillars of sustainability: environmental, economic and social factors are conceptually important aspects to be developed in engineering education. Complexity of the concept has opened up space for flexibility in designing a sustainability course in engineering education. This flexibility is demonstrated by the sustainability courses or sustainability-related courses that are offered all over the world in various engineering fields.

Sustainability is defined beyond the integration of the three pillars. It is about balancing the integration of those three key factors. However, the balance of integration of sustainability is not necessary tied to a single course but rather to the program as a whole. A sustainability course that emphasizes the environmental pillars will be in a perfect equilibrium with other sustainability-related courses that emphasize the other pillars. This flexibility of the design can be characterized into the third dimension: the approaches dimension.

The third dimension is also derived from the general model for sustainability by Martins, Matta and Costa (2006) and Lourdel et al. (2005) representation of sustainable development.

Table 5.7 Comparison of Arsat´s and Lourdel´s approaches to sustainability

Arsat´s representations	Lourdel´s representations
Singular	Environmental
	Social
	Economic
Dialectic	Environmental with social perspective
	Environmental with economic perspective
	Social with environmental perspective
	Social with economic perspective
Consensual	SD consensual approach

Singular approach

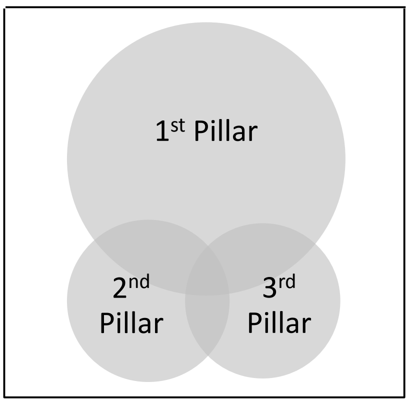

Figure 5.8 Singular approach: focusing on one pillar

The singular approach is described as sustainability courses that emphasize a specific pillar instead of a holistically blend of the three pillars together in a single course. Figure 5.8 and Table 5.7 demonstrate that the singular approach is equivalent to environmental, economic and social approaches. A course that can be categorized as a singular approach is a course offered at most universities in Malaysia. The course aims to develop students´ understanding of the sustainability concept by the introduction of the impact of engineering interventions in terms of the engineering ethics, moral and values. An example of the singular approach can be seen in Lourdel et al. (2005). Most of the course content has been designed to emphasize on environmental issues in engineering works and a small portion to introduce sustainable development concept.

Dialectic approach

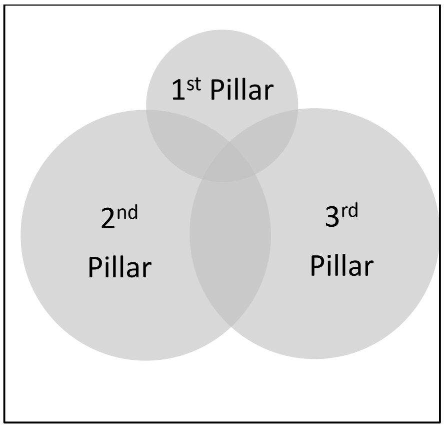

Figure 5.9 Dialectic approach: focusing on two pillars

The dialectic approach is defined as an approach that blends two pillars of sustainability to be the major learning component. A combination of the environmental with the social perspective is one of the possible combinations that can be made as an approach to sustainability. This is sometimes characterized as a dialectic approach, where the course targets are to influence students´ attitudes and practices (social perspective) in their daily life to be more environmental sensitive (Erdogan and Tuncer, 2009).The course is also a students´ platform to discuss real life cases (social perspective) from the street that they learned during a field trip. These activities on engagement to real story from street provide personal view of environmental issues (Erdogan and Tuncer, 2009). Lourdel also has presented four possible combinations of dialectic approach in his work as in Lourdel et al. (2005).

Consensual approach

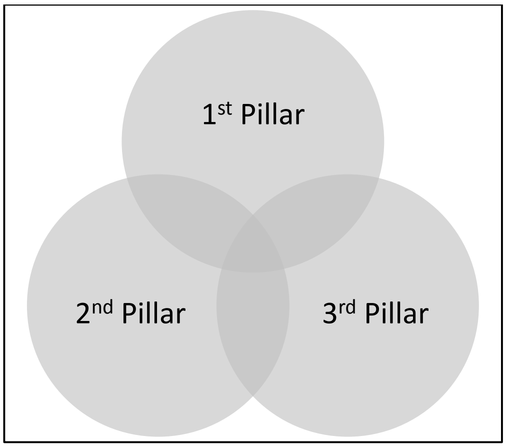

Figure 5.10 Consensual approach: the three pillars are fairly balanced

The consensual approach is an approach where learning objectives and course contents for sustainability course are fairly balanced in the integration of the three pillars. The combination of pillars can be viewed as an example in both studies by Russell, Legge & Petrolito (2009) and Kemppainen, Veurink & Hein (2007).

In terms of learning objectives and course contents, both courses presented in Russell, Legge & Petrolito (2009) and Kemppainen, Veurink & Hein (2007) have successfully balanced the three pillars in a single course without compromising the core knowledge of the engineering curriculum. For example, Kemppainen, Veurink & Hein (2007) course provides core engineering knowledge (*e.g.* computational skills, engineering problem solving method), economic (*e.g.* economic impact of the greatest engineering achievement in 20th century), environmental (*e.g.* calculation on electricity consumption, carbon and ecological foot prints) and social aspects (*e.g.* engineering ethics and global perspectives on engineering solutions).

These courses also prove that there are various methods to incorporate the concept of sustainability into a single course. For example, the course presented by Russell, Legge & Petrolito (2009) incorporates sustainability by presenting the three pillars as three different modules for one course while Kemppainen, Veurink & Hein (2007) course blends all three pillars in one module. Evidently, there is flexibility in the course design that is related to the complexness of sustainability concept. Program coordinators and course designers have to produce a framework that will guide the education transformation.

Themes

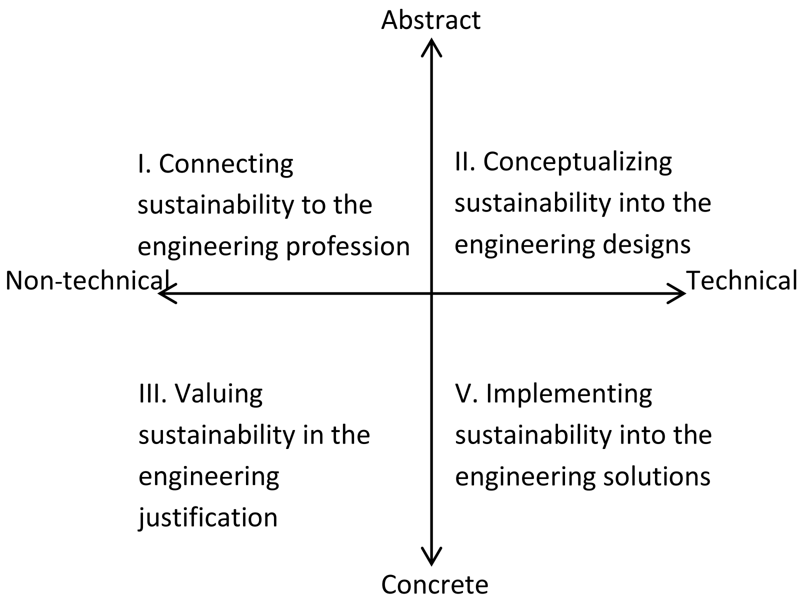

Figure 5.11 The key sustainability themes for engineering education

Incorporating the broad concept of sustainability into the existing engineering curricula is a very challenging process. The contents of the three pillars, environmental, economic, and social, are too broad to be fitted into a single engineering course or numbers of engineering courses. Despite these challenges, changes have to be done. Key sustainability themes can be a useful method to incorporate the three pillars into the existing engineering curricula. The sustainability themes are proposed without intention to narrow down the concept of sustainability; however, it is an effort to put the concept into a visualized representation appropriate for engineering education. There are four key sustainability themes which are illustrated in Figure 5.11.

Theme I - Connecting sustainability to the engineering profession

Theme I encompasses the components of sustainability which are the fundamental knowledge of sustainability, the engineering ethics/moral, the empowerment of engineer, the global issues and the local issues. These sustainability components that focus on non-technical contexts and abstract concepts are commonly incorporated in engineering education as an introduction for engineering students to view the concepts of sustainability. Theme I contains the components of basic knowledge, principles, concepts and issues that give a general picture of SD. These components are important information for students to understand SD concepts and we believe by connecting SD into the engineering profession, the students could increase their understanding and eventually they have a strong foundation on SD concepts.

Theme II - Conceptualizing sustainability into the engineering designs

Theme II represents the conceptualization of SD concepts into an engineering design. The components, which are categorized in Theme II, exemplify the integration of SD into the technical contexts and in abstract concepts. The components are the holistic approach/integrative approach towards sustainability and the concepts of green/ecology technology. Theme II includes the components that are more complex, interdisciplinary oriented and have high level of abstraction. The components require students to interconnect various perspectives and approaches of SD. At the same time, the components also require students to interrelate the components of SD with technical perspective. Therefore, we propose that students could gain a lot of understanding if they could apply the SD concept in their engineering design.

Theme III - Valuing sustainability in the engineering justification

Theme III includes the issues related to environment, resources and eco-system, social rights/value, social equity, citizenry, economic and stakeholders. These components are predominantly categorized as non-technical contexts and concrete concepts for engineers. Theme III encompasses the components of sustainability that are more complex and more often create conflicts when it comes into implementation compared to Theme I and Theme II. In order to understand these components, students are not only learning on the factual knowledge and conceptual knowledge but experiencing and employing the components into engineering process *i.e.* an evaluation process. Valuing these components in any engineering evaluation process can be a huge challenge to engineering students and even engineers. However, these components are crucial to be put in consideration of the engineers to justify their decisions. We propose that these components are incorporated in engineering curricula and designed therefore students could value it in their engineering justification.

Theme IV - Implementing sustainability into the engineering solutions

Theme IV represents the implementation of SD concepts into the engineering solutions. Theme IV encompasses the components such as environmental assessments, quality in engineering as well as green or ecology technology. The criteria of this theme predominantly focus on integrating components of sustainability into technical contexts and concrete concept. These components also could be categorized as procedural knowledge. The knowledge requires students to experience how to apply and understand where to use it. Thus by implementing the knowledge such as environmental assessments in engineering solutions, students will obtain the knowledge efficiently and gain the skills of employing the knowledge into engineering contexts.

5.8 Development of instruments

So far, the researcher has explored the real world practices by collecting the selected i) previous studies and ii) online documents around the globe. The data has been analyzed into three analysis processes i) analysis on the sustainability courses, ii) analysis on the concepts and principles of sustainability and iii) analysis on the course contents. These analysis processes provide understanding on what are the concepts and principles of sustainability that are important for engineering education, how is sustainability structured into the existing engineering curricula and how is sustainability contextualized into the existing curriculum so that it is compatible in terms of learning levels.

In order to provide practical point of views on how teachers in higher institution incorporate sustainability in engineering curricula, the researcher has collected data from the experienced experts and teachers around the globe. The data are also expected to provide explanations on why is sustainability important for engineering education, why is sustainability needed to be contextualized and why is the course structured in such ways. The following discussion demonstrates the process of developing the instruments.

Ranking task as an instrument for collecting data

In earlier discussion, the researcher has proposed fifteen components of sustainability in engineering education. The outcomes from course contents analysis are also evidences to the contextualization of sustainability where some components of sustainability become more important to some teachers but less important for other teachers. To understand further on the aspects of the importance of sustainability and the contextualization of sustainability, the researcher has developed an instrument that has a capability to corroborate the relationships amongst variables (in this case the components of sustainability) and elicit the teachers´ perception on the concepts.

Using ranking task as an instrument for data collection, the respondents have to rank all components of sustainability from the most important (rank 1) to the least important (rank 10). The respondents are simultaneously required to use their working memory for this kind of data collection technique. It is a mental system where the respondents have to hold several components of sustainability, understand the words, and manipulate the components based on its rank of importance. According to Miller (1956), the limit capacity of working memory (associated with short-term memory) can be quantified for about seven and up to nine words, pictures and units. Therefore, the researcher has regrouped the components of sustainability to comply with the limitation of working memory and designed the instrument by employing "loose cards" method as depicted in figure 5.12. So that the respondent do not have to memorize the components but instead moving around the cards on the ranking board. As a result, the components has been grouped into ten components (Pilot study for the instrument will be discussed in appendix E.1)

1. The fundamental concepts of sustainability
2. The engineering ethics
3. The knowledge of environmental management
4. The knowledge of environmental assessments
5. Engineering solutions based on economic aspect
6. Engineering solutions based on criteria set by stakeholders
7. Engineering solutions considering the resources and eco-system
8. Engineering solutions in terms of quality
9. Engineering solutions for global problems
10. Engineering solutions for local problems

Together with ranking exercise, the respondents were also recommended to think aloud while they rank the components. It is one of the methods that elicit the respondents´ perceptions and factors that influence the outcomes of the ranking task.

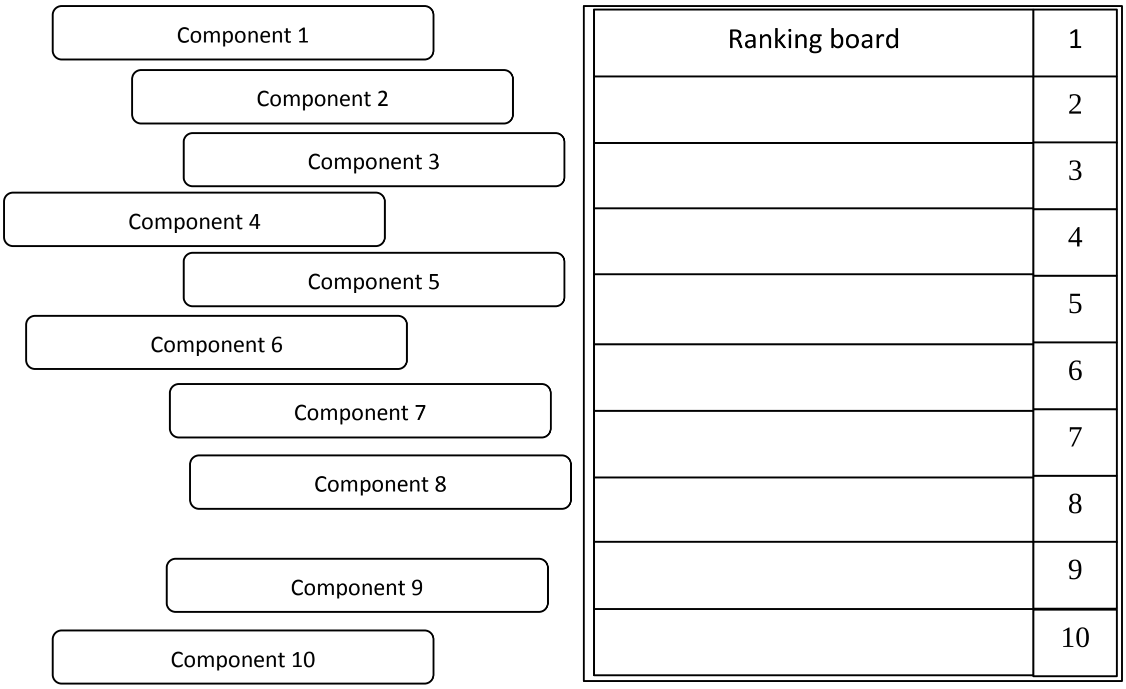

Figure 5.12 Illustration of ranking task as an instrument

Structured interview and semi structured interview as instruments for collecting data

A qualitative data collection technique was chosen to elicit the perception of teachers on the concepts of sustainability in engineering education and to find out their experiences in incorporating sustainability in engineering curricula. With a characteristic of interview as a tool that is purposely to obtain a special kind of information (Merriam, 1998) which is "in and on someone else´s mind" (Patton, 1990, p. 278 through Merriam, 1998, p. 71), interview is the best tool to provide data that address the objectives of the research. As Merriam explains:

> *Interviewing is necessary when we cannot observe behavior, feelings, or how people interpret the world around them. It is also necessary to interview when we are interested in past events that are impossible to replicate* [pp. 71].

The researcher has designed a set of structured questions that are purposely to elicit the teachers´ perceptions on sustainability. The questions were structured where the teachers (respondents) have to reflect based on their responses on the ranking task. The response will provide more data that explain what do they perceived on the concepts of sustainability in engineering education, why some components of sustainability are more important to engineering education compared to others, and why are some of the components of sustainability perceived less important for engineering education.

The questions for the structured interview are depicted as in the followings:

1. Why do you think component in the first rank is the most important for learning sustainability in engineering education?
2. Why do you think components in the first, second and third are the highly important components for learning sustainability in engineering education?
3. Why do you think component in the last rank is the least important component for learning sustainability in engineering education?
4. Why do you think components in the rank of 8, 9 and 10 are the least important for learning sustainability in engineering education?
5. Based on your experiences, do you want to suggest other components that are important for engineering students to learn about sustainability?

The researcher also has designed a set of questions for a semi structured interview session with the respondents. The questions are aimed to explore the teachers' experiences in incorporating sustainability into engineering curricula. The semi structured interview, as Merriam (1998) explains:

> *"In this type of interview either all of the questions are more flexibly worded, or the interview is either a mix of more and less structured questions. Usually, specific information is desired from all respondents, in which case there is a highly structured section to interview. But the largest part of the interview is guided by a list of questions or issues to be explored, and neither the exact wording nor the order of the questions is determined ahead of time. This format allows the researcher to respond to the situation at hand, to the emerging worldview of the respondent, and to new ideas on the topics"* [pp. 74].

The researcher has constructed the questions based on the findings gathered from the three analysis processes. It has been designed by including questions related to the course structures and course contents as well as other important components of course design such as teaching strategies and assessment techniques. The semi structured interview was planned by posting a structured question in the beginning of the session and followed by unstructured questions. For example, in order to explore the strategies the researcher will ask a general question such as how do you (the teachers) incorporate sustainability into the curriculum. Based on the response from the teacher, the researcher will lead the interview to the questions that are related to the response. For example, if the teacher is using a strategy that is in the same properties with one of the models of course structure (*e.g.* integrated model), the researcher will ask more questions related to the model. The interview guideline in Appendix B.1 shows the overall process taken by the researcher for the interview session.

5.9 Analysis and results from ranking tasks

The interview sessions with experts and teachers began on February 2012 and ended on December 2012. A total of 17 respondents from seven countries (Spain, France, Switzerland, The Netherland, Denmark, India and Malaysia) have participated in the study. Table 5.8 depicts the summary of rank for components of sustainability. It shows that eight experts (47%) rank the fundamental of sustainability as the most important component of sustainability in engineering education. The components of sustainability are labeled as follows:

A = The fundamental concepts of sustainability
B = The engineering ethics
C = The knowledge of environmental management
D = The knowledge of environmental assessments
E = Engineering solutions based on economic aspect
F = Engineering solutions based on criteria set by stakeholders
G = Engineering solutions considering the resources and eco-system
H = Engineering solutions in terms of quality
I = Engineering solutions for global problems
J = Engineering solutions for local problems

Table 5.8 Number of experts ranked on the importance of sustainability components

Rank	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
1	8	2				3	2	1	1	
2	4			2		1	4	2	4	
3			5	1	2	1	3		3	2
4		3		6	3		2	1	1	1
5	1	1	7			1	2	1	2	2
6	1	3		3		3	1	2	1	3
7	1	2	3	1	3	1	1	1	2	2
8	2	2			3	2	1	5		2
9		1	1	2	4	2		3	1	3
10		3	1	2	2	3	1	1	2	2

The researcher however could not state the second most important component and the subsequent rank because the table shows that the responses of sustainability components (except component A) are distributed to almost all rank. Thus, the Friedman test statistic was applied to bring out the complete rank of sustainability components.

In the ranking task, 17 sustainability experts (n = 17) rated 10 components of sustainability (k = 10) based on its importance to engineering education. By taking Friedman test as analysis method, the researcher can identify if any component of sustainability are ranked consistently higher or lower than the other components.

Assuming that, all components of sustainability are equally important. As a null hypothesis, the mean rank for all components will be (k+1)/2, which is 5.5.

From the test, the data is statistically manipulated as the followings:

$S_{bg(R)}$ = the squared deviate for any particular group mean

= n (Observed mean – Null mean)

$SS_{bg(R)}$ = between-groups sum of squared deviates

X^2 = Chi square value

Table 5.9 Analysis of data using Friedman test – All experts

Experts	A	B	C	D	E	F	G	H	I	J	ALL	$SS_{bg(R)}$	X^2
1	2	1	3	4	7	8	5	6	10	9			
2	7	8	5	6	3	1	4	2	10	9			
3	2	9	3	4	7	1	10	8	5	6			
4	2	1	3	4	9	10	7	8	5	6			
5	1	7	5	6	8	10	2	9	3	4			
6	2	6	5	4	10	9	3	8	1	7			
7	1	4	3	2	9	10	8	7	6	5			
8	5	10	3	4	7	8	1	6	2	9			
9	1	6	7	4	9	5	3	8	2	10			
10	1	5	7	9	8	6	4	10	2	3			
11	1	4	10	9	8	3	2	5	7	6			
12	1	4	5	6	10	2	3	9	7	8			
13	8	10	5	2	4	1	6	9	3	7			
14	1	10	7	3	4	6	5	2	9	8			
15	6	8	5	7	4	9	2	1	3	10			
16	1	7	5	10	9	6	2	8	4	3			
17	8	6	9	10	3	7	1	4	2	5			
n	17	17	17	17	17	17	17	17	17	17	170		
SUM	50	106	90	94	119	102	68	110	81	115	935		
Observed MEAN	2,62	5,77	4,92	4,92	7,62	5,69	4,46	7,31	4,85	6,85	5,50		
$S_{bg(R)}$	141,46	1,23	5,66	5,66	76,07	0,63	18,33	55,55	7,27	30,81		342,67	22,59
Null MEAN	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,5	5,5			

The value for observed mean and null mean are plotted into line graph as depicted in Figure 5.13. The figure shows that component A has the lowest observed mean rank compared to others. The second lowest observed mean is component G and the third lowest is component I. The figure also shows that component E has the highest observed mean rank with over 7 and component H has the second highest observed mean rank with slightly over 7. Translating the result into the rank of importance, the research outcomes shows that most of the sustainability experts rank the components of sustainability from the most important to the less important for engineering education as listed below:

1. The fundamental concepts of sustainability
2. Engineering solutions considering the resources and ecosystem
3. Engineering solutions for global problems
4. The knowledge of environmental management
5. The knowledge of environmental assessments
6. Engineering solutions based on criteria set by stakeholders
7. The engineering ethics
8. Engineering solutions for local problems
9. Engineering solutions in terms of quality
10. Engineering solutions based on economic aspect

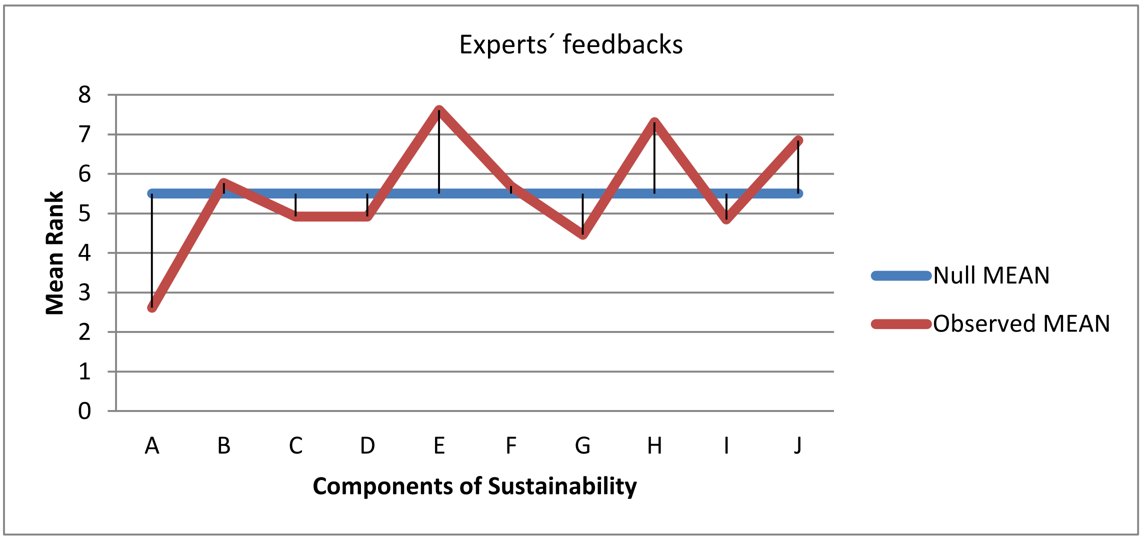

Figure 5.13 Comparison of mean – all experts

Figure 5.14 shows that the calculated X^2 indicates the probability value (p-value) is smaller than 0.5% (0.005). Significantly the outcome of the Friedman test shows that there is less than 0.5% chance to have a different outcome from the presented result in Figure 5.13. It is concluded that the observed differences among the mean rankings for the ten components of sustainability in engineering education reflect something more than a mere random variability, and something more than a mere chance coincidence among the judgments of the sustainability experts.

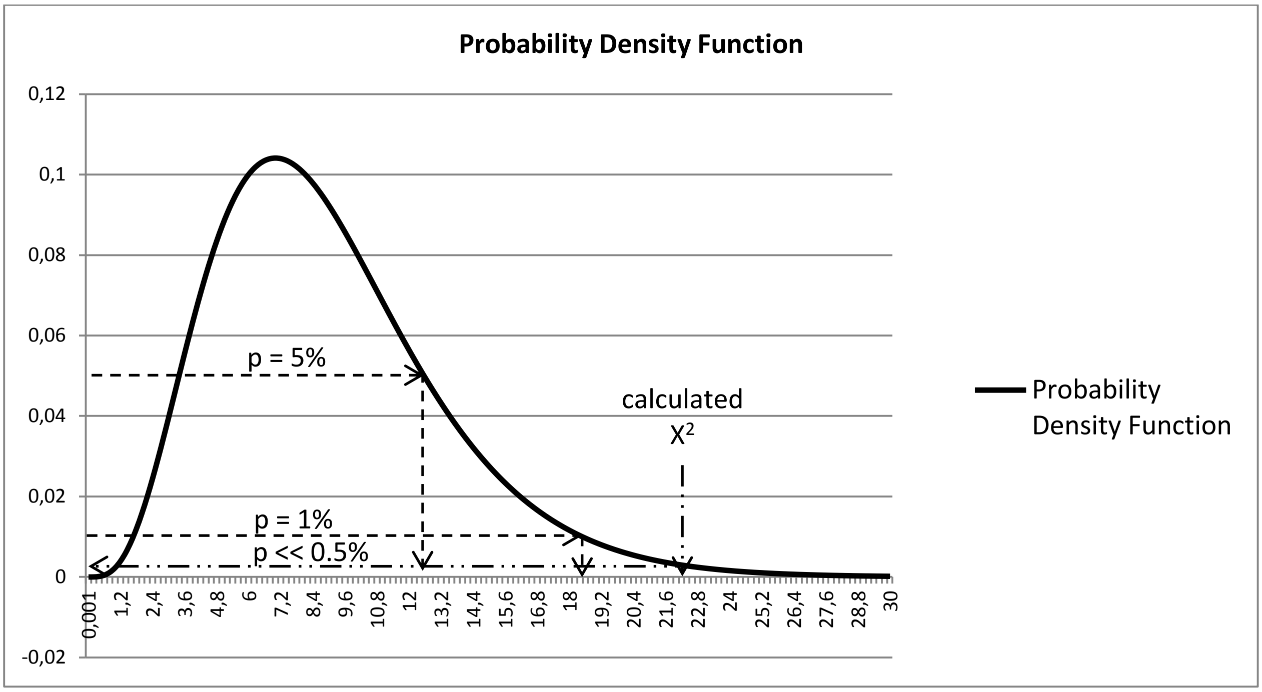

Figure 5.14 P-value for the observed mean ranks

The ranking list demonstrates to what extend the equilibrium idea of sustainability is implemented or perceived important amongst universities. The idea of equilibrium in the concept of sustainability is by valuing equally the environmental, social and economic dimensions. The ten components provided in the ranking task collectively represents the equilibrium idea of sustainability. Some of the components are representing these three dimensions while other components are highlighting one or two dimensions. By positioning a component on the higher rank, it will indicate that particular component is perceived more important than the others. In addition, the ranking list also provides understanding of the respondent´s perspectives on each dimension of sustainability concept.

The result shows that most of the respondents ranked the environmental-related components on the higher position e.g. engineering solutions considering the resources and ecosystem, the knowledge of environmental management and assessment. This could indicate their believed of the importance of environmental dimension compare to the others. Therefore, environmental dimension frequently incorporated in engineering curricula as an approach to sustainability. However, the result shows that most respondents considered the fundamental concept of sustainability, which including all three dimensions, is important (in the top rank) for engineering education. It indicates the awareness of the respondents on the idea of equilibrium in sustainability concept.

The result also shows that the economic-related components were ranked at the least position e.g. engineering solutions in terms of quality and engineering solutions based on economic aspect. This is due to the perception of respondents that believed economic dimension is has been highlighted and well represented in the engineering education compare to the other dimensions. The perceptions of the respondents towards the ten components of sustainability during the ranking tasks are (by observation) depending on several factors. The respondents ranked the components and made self-reflections (by thinking aloud and structured interview sessions) by connecting the results with their experiences either in teaching, developing sustainability courses or conducting researches.

1 Process of learning

Most of the respondents ranked the components of sustainability based on the process of learning. A process where the students have to understand a basic knowledge of sustainability such as concepts, principles and its relation to engineering (*e.g.* engineering ethics) at the beginning and develop their understanding by applying the knowledge into the context of engineering (*e.g.* environmental assessments and engineering solutions by considering criteria set by stakeholders). As one of the respondents explains

"First, they (the students) have to understand the concepts. As their interest develops, then they start to explore the knowledge….. the exploration is based on discipline order….." (Expert 6)

Most of the teachers perceived the basic concepts of sustainability as highly important for engineering students, as a foundation and a preparation for students to acquire higher order learning levels. Sustainability components such as "engineering solutions considering resources and eco-system" and "engineering solutions for global problems" are perceived as knowledge that demands higher learning level and needs prerequisite knowledge either sustainability knowledge or engineering knowledge. Therefore, in the effort to incorporate sustainability in engineering curricula the components of sustainability that offer lower level of learning are accepted as highly important compared to the components of sustainability with higher learning levels.

2 Engineering process

Some of the respondents ranked the components of sustainability by reflecting on the engineering process, either in the real-works perspective or engineering laboratory/design perspectives. For example, an engineer or a group of engineers need to identify the criteria set by stakeholders. It is assumed as the driver for the engineering design. The next process could be designing a solution that is cost effective and highly efficient. As these requirements are met, engineers can make some assessments in terms of its effects on the environment.

The perceptions on the importance of sustainability components can be seen in the following excerpt:

"Throughout engineering design you have to have ethics. Of course engineering ethics are important, but when you design a product, you have to consider customer needs. In this process of developing the products, then you have to make sure safety is there, and everything is there and there are no adverse effects on customer. If we are not ethical, of course our products are considered to have no quality" (Expert 2)

In this case, the teacher was explaining why "engineering solutions considering criteria set by stakeholders" is more important than "engineering ethics" by connecting the importance of sustainability components into the process of developing engineering products.

3 Urgency issues

"We have to go back to the reason why we have sustainability concept. Now we are facing global problems on resources depletion, very serious problems on pollution that affect our ecosystem. If we keep our life style as what we practice now, we require more resources in future and our globe is not able to provide the resources in the future. For example, in case of un-renewable materials, we keep utilizing or we use them continuously because of industrialization. That will cause to the depletion of resources and damage our ecosystem.

So what we have to do with sustainability is what we have to sustain, therefore at the same time we could fulfill current generation´s requirement and keep something for future generations" (Expert 5)

The excerpt is one of the examples on how the teacher reflects the importance of the components of sustainability for engineering education by the urgency issues. The teacher pointed out the issues of environment which are the origin of sustainability concepts that need to be put in the top priority. The components have been ranked regardless of the complexity of the knowledge for learning, levels of learning and its connection to engineering design. It is a reflection on the issues that demand immediate action or attention by the future engineers.

4 Requirement for accreditations

Incorporating sustainability into engineering education is perceived important by some of the respondents for accreditations, internationalization and recognition. In fact most universities are transforming their engineering curricula by incorporating sustainability as parts of or driven by the accreditation needs. For instance, the document called `Graduate attributes and professional competencies´ by International Engineering Alliance (2009), explicitly demands the graduates from the members of the alliance to "understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development". The respondents have also highlighted some particular issues of sustainability that are related to environmental aspects and social aspects which is by observation highly influenced by the criteria stated by the accreditation bodies. This also explains why most of the components of sustainability that are highly related to economy aspects are perceived less important by the respondents.

5 Industrial needs

The demands on green technology, eco-technology, and other kinds of sustainability-sound approaches as attributes for an engineering in industry become the center of attention for some respondents. The needs of sustainability attribute in industries are usually magnified through the enforcement of rules and regulations by the authorities in industrial sectors. The attributes such as understanding and be able to apply ISO 1040, Green Building Index (GBI) or green engineering design principles are important for engineering education. Therefore, some of the respondents ranked "environmental management" and "environmental assessments" as one of the important components.

The outcomes from the semi-structured interviews demonstrate the strategies taken by the respondents in order to incorporate sustainability into their own engineering courses. Most of the respondents have described and explained the strategies for the incorporation, and there are similarities between the strategies from the document analyses (presented in Sub-chapter 4.3 and 4.7) and the strategies shared by the respondents. However, there are some important remarks from the interview session that will strengthen the strategies presented in the earlier chapter.

1 Linking the existing course to the concepts of sustainability

"I am starting to teach the introduction of sustainability in engineering courses. So what we think is, we don't want to realize with very specific lecture about sustainability but we want that at the end of the year students have sustainability achievement in their level. To do that, we already have lectures about economic aspects, about ergonomic, about marketing, and others. What

we want to do is to create a link between those different lectures. Perhaps we will at the beginning, when students arrived, introduce the concept of sustainability. Then they will have a different lecture at the end of year to put a final lecture of sustainability, to create the link" (Expert 13)

2 Developing research on sustainability for knowledge generation

"…because some information is missing about sustainability in the company. Because we don't have so many PhD industries, we start with new curriculum here, with a part of their time in school and a part of their time in their company, and we create specific curricula for them about sustainability. So we hope that they will be in companies trying to solve sustainability issues/problems and we could expand and incorporate this experience in the curricula. So we need to construct knowledge about sustainability, and we don't want to only focus on theoretical we need to catch the knowledge in reality (practice)" (Expert 13)

5.10 Conclusion – Inputs to designing a framework: Contextualizing sustainability and structuring course

A wide range of course design and complexity of sustainability concept has opened up dimensions to characterize course structures and course contents for the development of sustainability courses. Based on the conceptual framework proposed by Arsat *et al.* (2011), the three dimensions (model, orientation and approach) of characterization have been further explained and discussed. In this chapter, the dimensions have been further developed by introducing sustainability themes and competencies. Therefore, there are five dimensions of sustainability incorporation in engineering curricula. The dimensions can provide perspectives on constructing and designing sustainability course in engineering education. Models, orientations, approaches, sustainability themes and components show evidence of variation in interpretation of sustainability concepts in engineering education. Each of the dimensions has different aims and ways for design and implementation.

In practices, the concept of sustainability has been contextualized according to the dimensions of sustainability incorporation. For instance, the concept of sustainability will be contextualized into specific focus if it was aims to incorporate sustainability by employing singular approach. In this approach, the concept of sustainability can be incorporated into engineering curricula by focusing on the aspect of environmental or social or economic. In other example, sustainability also can be contextualized according to the key sustainability themes. These themes represent where the knowledge related to the concept of sustainability can be contextualized according to the needs. It can be either to connect sustainability into engineering professions, to conceptualize sustainability in engineering designs or to the extent of sustainability implementation in engineering solutions.

Through the empirical studies the concept of sustainability has been clustered into ten components. The result shows that the fundamental concept of sustainability, engineering solutions considering the resources and ecosystem, and engineering solutions for global problems are perceived very important components by the respondents for engineering education. From the interview sessions, the rank is developed from several factors which are process learning, engineering process, urgency issues, requirement for accreditations and industrial needs. It shows respondents´ reflections on their experience as a teacher and practitioner. In addition, these factors provide understanding in general on the considerations that has been taken by the respondents to incorporate sustainability in engineering curricula.

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Chapter 6

Phase two: Highlighting positive practices

6.1 Introduction

The process of analysis and designing a framework continues in the phase two. It is a phase where the research is focused on case studies in two university, so that the findings are able to highlight positive practices as well as contribute to the effort of developing the framework and tools for course evaluation (presented in the next chapter). This chapter is organized by presenting the results of the programs and courses inventory from Universiti Teknologi Malaysia (UTM) and Aalborg Universitet (AAU). The chapter also presents the procedures to develop the research instrument for this phase and the research outcomes at both universities. The following figure illustrates the paths of presentation of this chapter.

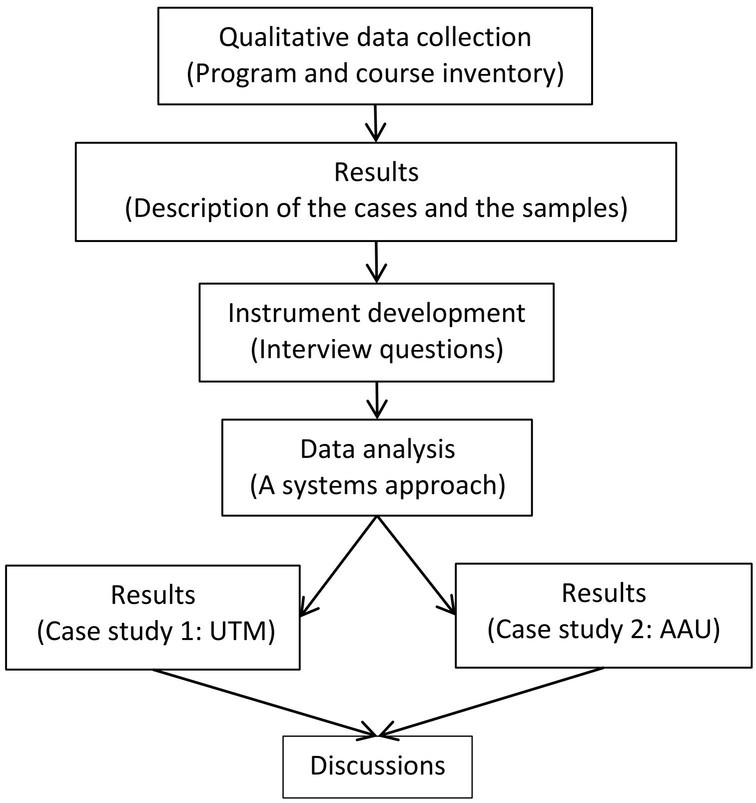

Figure 6.1 The paths of presentations for phase 2

6.2 Engineering education and Sustainability at two universities – UTM and AAU

In Malaysia, engineering education has gradually shifted from traditional education system to outcome based education (OBE). Board of Engineers with association of Engineering Accreditation Council (EAC) has driven the shift since 1999 by the introduction of eleven generic attributes for engineering graduates (Aziz et al., 2005). In Malaysian Engineering Education Model, there are five important criteria that Aziz et al. (2005) has identified. The criteria are "*i) **scientific strength,** which provides engineers who are innovative, able to work in research and development activities, and adaptable in different fields, ii)**professional competencies,** which provide engineers who are able to identify, formulate, and solve engineering problems, responsible professionally, and able to use techniques, skills, and modern engineering tools for engineering practices, iii)**multi-skilled,** which provides engineers who are able to work in different engineering fields and function in multidisciplinary work/teams, iv)**well respected and potential industry leader**, which provide engineers who are able to understand the impact of engineering solutions in a global/social context, knowledgeable of contemporary issues, able to communicate effectively and be involved in community or social projects, v)**morally and ethically sound**, which provide engineers who understand ethical and moral responsibility".* Through the Malaysian Engineering Education Model and OBE, active learning methods such as project based learning have been widely implemented amongst teachers in Malaysian engineering schools as well as in UTM.

In Denmark, problem based learning was founded in the early 1970s by institutionalizing the problem and project pedagogies in two universities, Roskilde University Centre in 1972 and Aalborg University in 1974 (de Graaff and Kolmos, 2007). Learning by doing and experimental learning were two of the central principles (de Graaff and Kolmos, 2007), and the students were to work in collaboration with teachers and others to explore and solve a problem in close relation to the social reality in which it exists (Berthelsen et al., 1977). Thereby, the societal context was a key consideration from the very beginning, drawing from Mills (1959) among others and his visions of social imagination.

As such the path to incorporate sustainability was established, it was not before the Brundtland Commission, chaired by Gro Harlem Brundtland, published their famous report "Our common future" (Brundtland Commission, 1987) in the late 1980s that a sustainability discourse was developing at the Aalborg campus. In the 1990s sustainability started to show explicitly in curricula. One of the more comprehensive initiatives were taken by the former study director Mona Dahms, being responsible for a gathered first year of all educational programs at the Faculty of Engineering and Science. In this first year, students were working in inter-disciplinary groups on projects for sustainability. This example still stands as the most throughout incorporation of sustainability at AAU. Today sustainability is incorporated as a patchwork of practices across faculty, whereas management is now determined to gather and develop these practices in order to secure ESD in all programmes.

UTM on the other hand, has a long history on conducting sustainability researches especially in the field of renewable energy, water, and sustainable construction. Some of the components of sustainability such as engineering ethics, environmental management and environmental assessments have been incorporated in several engineering curricula couple of decades ago. It was by individual initiatives and implemented by a small group of teachers. The approach on sustainability in UTM started to spread tremendously by the establishment of Sustainability Research Alliance (SRA) and the Office of Campus Sustainability (OCS) around 2008. For instance, SRA in UTM has become a huge sustainability community by participations of individual researchers, research groups and centres of excellence (COE) from wide range of disciplines. Currently there are five COEs which are i) Process Systems Engineering Centre (PROSPECT), ii) Centre of Real Estate Studies (CRES), iii) Kajian Alam Bina Melayu (KALAM), iv) Institute of Geospatial Science and Technology (INSTeG) and v) Centre for Innovative Planning and Development (CIPD) that are working together aiming for comprehending national or international sustainability issues and providing sustainable engineering solutions. The OCS on the other hand has different purpose. The OCS promotes sustainability in the campus not only in research activities but including other activities e.g. teaching and operation. According to Irina Safitri Zen, director of the OCS at UTM, *"the sustainable campus initiatives provide a good example on how an institution contributes comprehensively and concretely in sustainable development"* (NST,SEPT 28, 2013).

This chapter presents a piece of the patchwork of practices at the Faculty of Engineering and Science Aalborg University, to exemplify the incorporation of sustainability in a problem based learning environment. The case studies are related to engineering education and more specifically electronics. This chapter also presents the practices at Faculty of Chemical Engineering, Faculty of Mechanical Engineering and Faculty of Civil Engineering in UTM to exemplify the incorporation of sustainability and active learning methods in engineering education.

6.3 Results and discussions - Program and course inventories

In order to highlight university practices incorporating sustainability in engineering curricula, this study focuses on four engineering disciplines: mechanical engineering, civil engineering, electrical engineering and chemical engineering. In UTM, these four engineering disciplines have been established since 1972 and the faculties (where the faculties establishment is based on discipline) relatively have longer experiences in offering engineering programs as well as transforming their engineering curriculum for sustainable development compared to other engineering disciplines e.g. computer engineering and biomedical engineering. Therefore, the researcher is not only able to describe the sustainability courses conducted by the teachers but also underline their experiences incorporating sustainability in their engineering curricula.

Case studies in Universiti Teknologi Malaysia

The case studies presented in this chapter were carried out from March until May 2012 at Universiti Teknologi Malaysia, Malaysia. The studies aim to understand the teacher's experiences and the implementation of sustainability related courses. In the studies, eight interview sessions were administered and selected documents were collected.

In UTM, there are in total 46 programs offered as undergraduate programs and 102 programs offered as graduate programs. Out of the total figures, 17 undergraduate programs and 38 graduate programs are in the field of engineering. Table 6.1 shows the result from programs inventory for sustainability courses and sustainability-related courses.

Table 6.1 List of programs that offer sustainability courses

No	Program	Faculty
1.	Bachelor of Engineering (Chemical)	Faculty of Chemical Engineering
2.	Bachelor of Engineering (Chemical-Bioprocess)	
3.	Bachelor of Engineering (Chemical-Polymer)	
4.	Bachelor of Engineering (Civil)	Faculty of Civil Engineering
5.	Bachelor of Science Industrial Biology	Faculty of Bioscience and Bioengineering
6.	Bachelor of Engineering (Naval Architecture and Offshore Engineering)	Faculty of Mechanical Engineering
7.	Bachelor of Engineering (Petroleum)	Faculty of Petroleum and Renewable Energy Engineering
8.	Bachelor of Engineering (Chemical-Gas)	

However, two of the faculties have declined to participate which makes the total programs reduced from eight to four programs. The programs are Bachelor of Engineering (Civil), Bachelor of Engineering (Naval Architecture and Offshore Engineering), Bachelor of Engineering (Petroleum) and Bachelor of Engineering (Chemical-Gas).

Table 6.2 shows the results of course inventory for the four engineering programs. The course inventory was a process where the researcher characterizes the courses that are offered in the four programs based on models, approaches and orientations. In Arsat, Holgaard and de Graaff (2011), sustainability course can be characterized in three dimensions which are models, approaches and orientations. The model of sustainability course could possibly be a stand-alone or integrated model in the engineering curricula. The sustainability course could also disciplinary oriented or interdisciplinary oriented and the course could also possibly be characterized as singular, dialectic or consensual approaches.

Table 6.2 Course inventory for engineering programs

Programme	Number of courses	Characteristics						
		Models		Orientations		Approaches		
		Stand-alone	Integrated	Disciplinary	Interdisciplinary	Singular	Dialectic	Consensual
Bachelor of Engineering (Civil)	10	1	9	7	3	9	0	1
Bachelor of Engineering (Naval Architecture and Offshore Engineering)	5*	NA	NA	NA	NA	NA	NA	NA
Bachelor of Engineering (Petroleum)	1		1	1		1		
Bachelor of Engineering (Chemical-Gas)	3		3	3		3		

Seven engineering courses were studied as examples of incorporation of sustainability in engineering curricula in UTM. The courses were selected based on the results from course inventory and accessibility for research study i.e. permission for data gathering. The courses in this chapter will be identified as cases in the remainder of this chapter. Table 6.3 shows the title of the courses for each case according to the entitled faculties.

Table 6.3 Sustainability courses in engineering programs

Case	Course title	Faculty
1.	Introduction to Engineering	Chemical & Natural Resources Engineering
2.	Civil Engineering Fundamentals	Civil Engineering
3.	Sustainability & Environmental management in Construction	Civil Engineering
4.	Environmental management	Civil Engineering
5.	Plant Design	Chemical & Natural Resources Engineering
6.	Offshore structures	Civil Engineering
7.	Sustainable Manufacturing and Product life cycles	Mechanical Engineering

Case studies in Aalborg Universitet

In this chapter, three project modules are presented as examples of progression of ESD practices in the study program of Electronics and IT. The three project modules emerged as the outcomes from program inventory, where the inventory was designed to identify a module that integrates sustainability. In the inventory process, each of the modules were thoroughly examined on the learning contents such as module objectives and expected learning outcomes i.e. knowledge, skills, and competencies.

The project modules are offered for first year student in the first semester and second semester and structured as Problem based and project organised Learning activities. Typically, the phases of a project module are that the students, within the frame of a pre-defined project unit theme, formulate an initiating problem (sometimes based on a catalogue of project proposals), then they move to problem analysis and based on that they formulate a narrower problem within pre-defined disciplinary boundaries. Taking the point of departure in this problem formulation and a methodological framework, they solve this problem and assess the proposed solution taking results of the problem analysis into consideration.

In this studies, the three project modules are as follows:

A. *Technological project work (P0 - approx. 5 weeks)*
This module is offered to provide students with an insight in a problem based learning environment and at the same time introduce basic concepts and applications in electronics and IT. The problem presented here is rather narrow within a technical frame of mind.

B. *Basic Electronic Systems (P1- approx. 10 weeks)*
This module is structured to provide a platform to enable students to be socialized into the electronics and IT-related engineering disciplines. Theoretical and practical works are combined, taking point of departure in a problem derived from a community or business context. This problem will be analyzed by decomposing the problem in sub-problems in order to select and formulate a technical problem that can be solved by using the theories and methods of microprocessor-based systems. The solution has to be an electronic system, incorporating a programmable computer and able to react to and/or control parts of its outside environment via selected actuators and sensors.

C. *Dynamic Electronic Systems (P2)*
In this course students will be taught through theoretical as well as practical work, based on a selected problem that will acquire knowledge within the electronic and IT related engineering discipline. However, here the students also have to use relevant methods within the field of Science, Technology and Society (STS), that demonstrates that they can contextualize a technical problem including relevant social contexts. Again, the problem will be analyzed through decomposition into sub-problems, but in this case the context of the problem is analyzed more in depth, which has implication on the formulation of the technical problem. In any case this technical problem has to be solved using electronic systems interacting with the surrounding environment. The final solution will then be evaluated at the

end based on evaluation criteria derived from the technical as well as the contextual analysis.

6.4 Results and discussions – Procedures to design an engineering course

Generally, designing or re-designing an engineering course requires consideration on many aspects. Course developers have to deal with resources (teachers, supervisors and experts), space and facilities aspects (internal aspects) and they also have to encounter external aspects such as stakeholders, national and international recognitions. The research outcomes (from the inventories of the programs and the courses) from both cases have shown that the process of designing and re-designing an engineering course are responses towards the requirements set by either accreditation bodies (UTM) or qualifications framework (AAU). Both accreditation and qualification entities have included the internal and external aspects as part of their requirements. It is therefore, the major aspects that have been contributed in curriculum design at UTM and AAU, which are illustrated by the following Figure 6.2 and Figure 6.3.

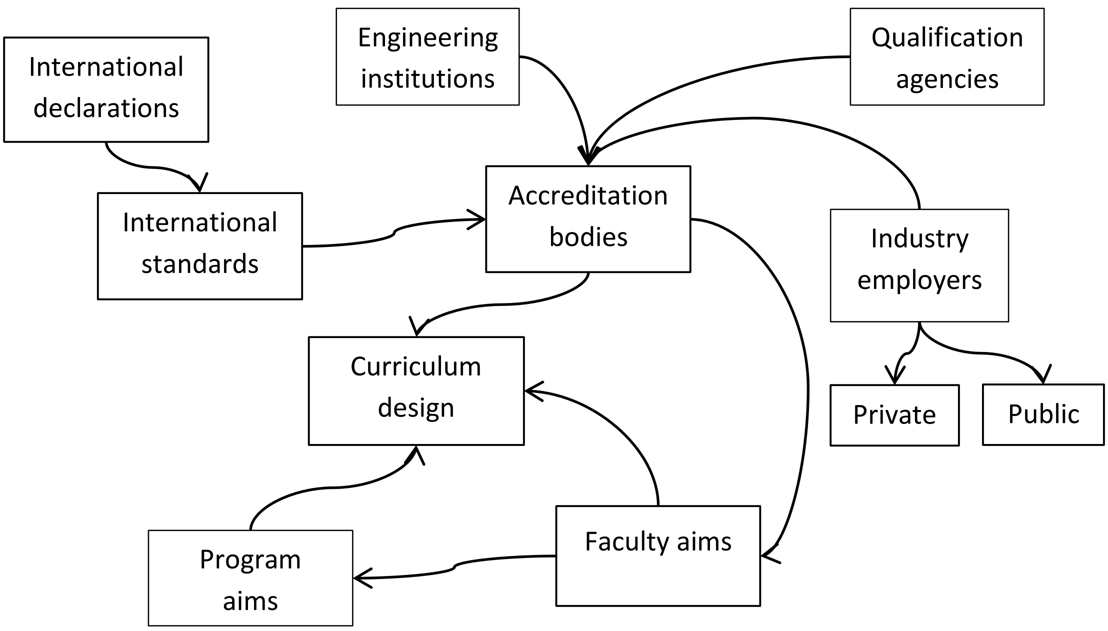

Figure 6.2 Major aspects in curriculum design at UTM

Figure 6.2 demonstrates that the accreditation bodies are the major aspects in designing a curriculum in UTM. These institutes are responsible to make decisions on the accreditation of engineering curriculum offered by the university and provide them policies and guidelines for the accreditation and international recognitions. The policies and the guidelines are developed by consulting various stakeholders such as engineering institutions, private and public industry employers, and qualification agencies. The policies and the guidelines also are responding to the international standards and the international declarations.

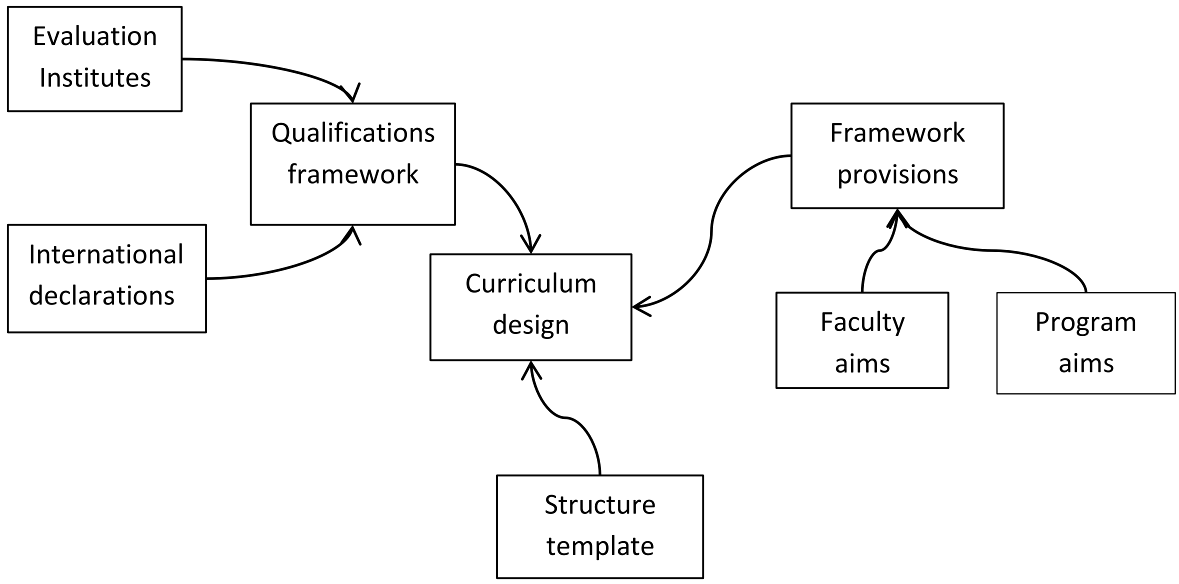

Figure 6.3 Major aspects in curriculum design at AAU

In AAU, the course/curriculum designer is required to refer to the national qualifications framework, the framework provisions and a structure template for designing or re-designing engineering curricula (The Danish Bologna follow up group, 2003). The qualifications frameworks have been developed by consulting evaluations institutes and considering international standards. The qualification framework provides a guideline for designer to face the external aspects including the students learning outcomes (competencies). The framework provisions on the other hand provide guidelines that are more focused on the internal aspects of curriculum design.

As Outcome-based Education (OBE) is employed throughout the curriculum, all programs and courses are designed to achieve the general aims and objectives. In particular, the courses will offer structured learning objectives (Course Learning Outcomes) which reflect the Program objectives or Program Learning Outcomes. Therefore to incorporate sustainability into the existing engineering curricula, managing sustainability competencies is important.

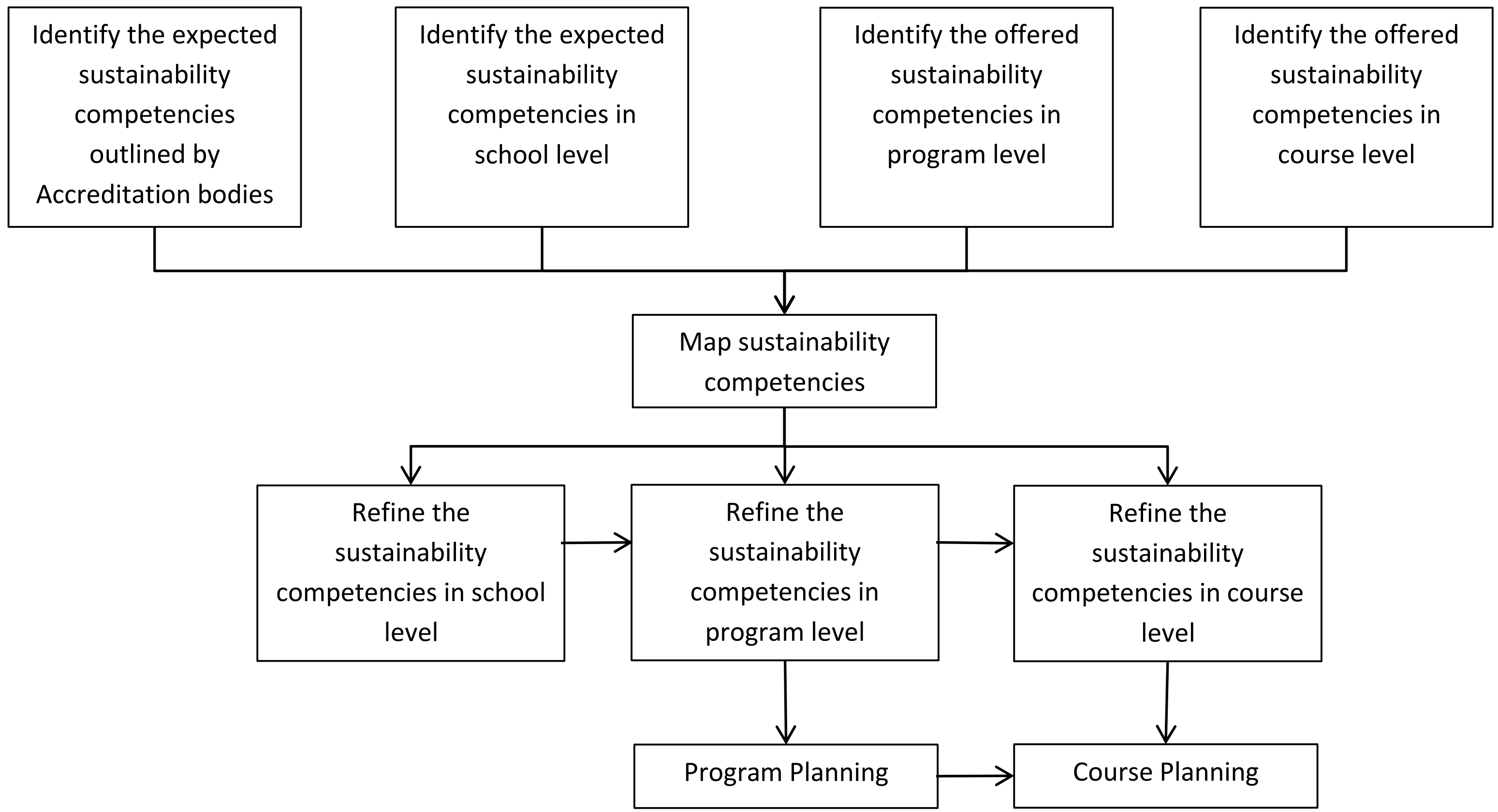

Figure 6.4 Managing sustainability competencies

To manage sustainability competencies, the expected sustainability competencies for the visionary course have to be aligned to the expected sustainability competencies outlined by accreditation bodies and planned by the school. The alignment of sustainability competencies can be done by mapping the expected competencies from all level (Accreditation bodies level, school level, program level and course level).The flow diagram below shows how the four levels are mapped and influence the process of refining sustainability competencies in every level, program planning and course planning.

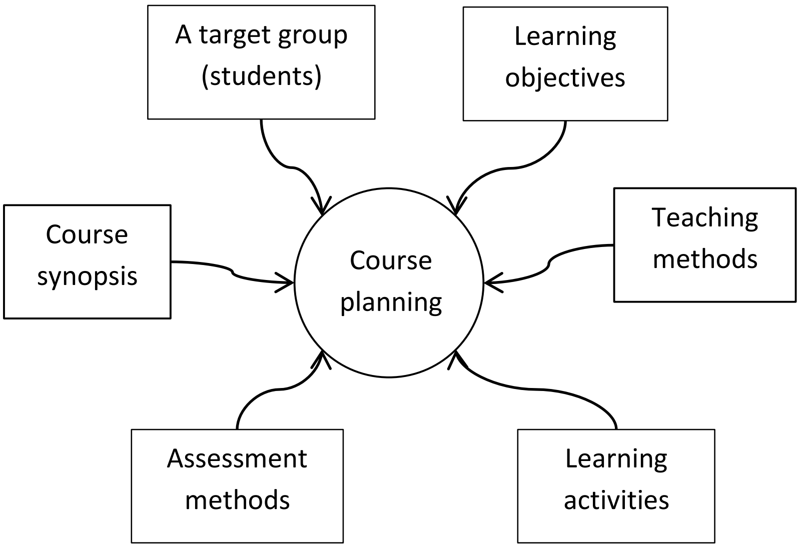

Figure 6.5 Common elements in course planning

By making an inventory of the programs and courses offered in both cases, the researcher has come out with a diagram that shows the common elements in course planning that are practiced by both universities. As depicted in Figure 6.5, the elements are i) course synopsis, ii) a target group, iii) learning objectives, iv) teaching methods, v) learning activities and vi) assessment methods. These six common elements are deemed important for course designer in planning their course as well as incorporating sustainability into the existing engineering course (re-designing process). However, the researcher could not provide on how these elements influence the process of incorporating sustainability. A follow-up research is needed to study in-depth in terms of the course development strategies, teacher´s experiences of teaching sustainability and students´ understanding on issues related to sustainability.

6.5 Instrument development

The instruments for phase two were developed to address the research questions and to fulfil the requirements of the research model for these case studies (see Chapter 3). The researcher decided to conduct a series of semi-structured interview sessions with course developers and teachers at both universities. This approach permitted the researcher to post structured questions as opening questions to the respondents (course developers and teachers). The structured questions were developed by taking the data from the program and course inventories such as the major aspects on curriculum design and the common elements in course planning practiced by both universities. The follow up questions however depends on the responses given by the respondents. In this manner, the researcher has opportunities to post questions that aim for explanations and clarifications from respondent´s experiences (Seidman, 1998). The following section aims to explain the outline and questions for the semi-structured interview sessions.

Expert background

A. *Would you please tell me about your background and working experiences in the field of sustainability in engineering education?*
B. *What do you think about education on sustainability at your university in general and in your department?*
C. *Have you led or participated in developing a sustainability course or reform the existing course to incorporate sustainability?*

These three questions are intended as opening questions to the respondents. The aim is to understand the education background of the respondents better, to understand the stand point of the respondent on the efforts of incorporating sustainability in engineering education and to signal the respondents the direction of the interview (understand the respondent experiences either as a teacher of the sustainability course or the designer of the sustainability course).

General information

A. *What is the course name?*
B. *When has the course started to be offered to students?*
C. *How many teachers are appointed for this course?*

These questions aim to raise awareness to the respondents on the particular course that they teach or develop. (Note that the researcher already has the basic information about the course(s) from the programs and course inventory).

From this point and forward, the questions are not posed exactly according to the structure, rather the choices of order and words are flexible, adapting to the natural flow of the interview.

Structuring the course

The next questions aim to identify the major aspects that are important for curriculum design and to elicit the reasons behind the course structure.

A. *Would you tell me the process taken to develop the course?*
B. *Based on the course outlines, I believe that the course was (re)designed to incorporate education about sustainability. Why do you choose to redesign the course in such a way (stand-alone model or integrated model)?*

Constructing learning objectives and course contents

A. *What are your opinions on the sustainability competencies that have been structured in the learning objectives?*

B. *Based on the course outlines, I believe that the course focuses more on (one pillar, two pillars or all three pillars are fairly balanced). Why do you choose to focus more on (one pillar, two pillars or all three pillars)?*
C. *How will this approach imply the concepts of sustainability?*

The structure of the interview aims to understand if there was a particular strategy taken by the respondent to incorporate sustainability competencies into the existing learning objectives. The questions also help the researcher to understand the implication of the selection of sustainability contents to the understanding of the concepts of sustainability.

Targeting the groups

In your course, do you have specific methods of choosing your target groups (the students)?

From this question, the researcher is able to understand why the teacher chose the students or specific year of engineering students to undergo the learning of sustainability. The question also could provide the researcher if there was a reason to combine two groups of engineering students from different disciplines.

Selecting teaching strategies

A. *What is the main teaching strategy applied in the course?*
B. *Why did you choose that particular teaching strategy?*
C. *Besides the main strategy, could you explain if there was other teaching strategy applied to the course?*

Most university teachers have a tendency to mix several teaching strategies into their classes. Therefore the questions are structured to explain the teacher´s selection on the teaching strategy and if the teaching strategy is related to the incorporation of sustainability.

Assessment methods

A. *What are the methods that have been used for assessment?*
B. *To what extent the assessments can reflect the students´ competencies?*

From these questions, the researcher could provide explanation on the selection of assessment methods and highlight if there was a specific method used by the respondents to assess sustainability competencies.

6.6 Analysis methods

In their works, Rompelman and de Graaff have presented the possibilities to analyse the existing world and synthesize `a new world´ with a system approach, and they also have explored the concept of system approach in an educational context (Rompelman and de Graaff, 2006). The system approach in this paper categorizes students in the centre of the teaching and learning process. Whereby, the other variables such as course contents are categorized as input factors; abilities, knowledge and skills are considered as output factors; and facilitation and teaching are considered as throughput factors. The reflections on the whole process are then seen as a feedback to re-design the system, see Figure 6.6

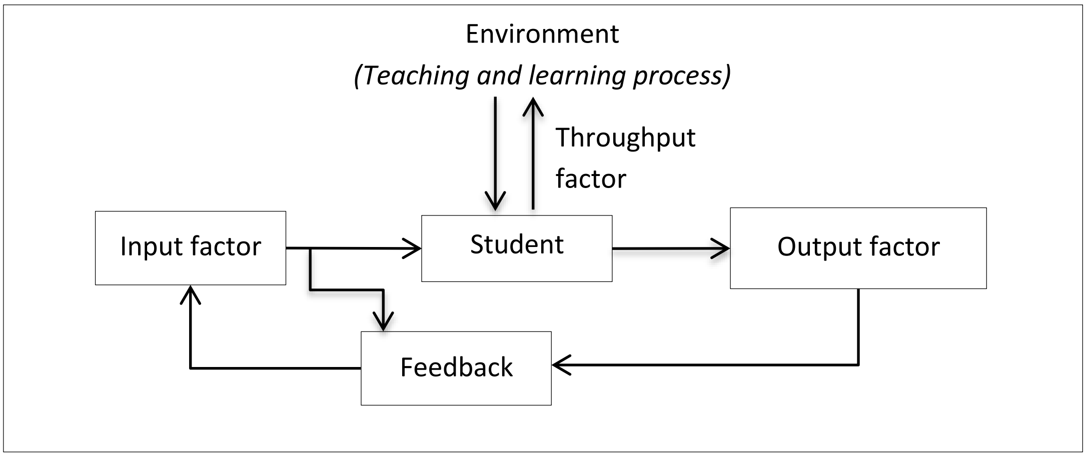

Figure 6.6 A system approach for analysing engineering curricula

In a similar model, Creemers and Scheerens have used an input-process-output approach, rather specific termed as a context-input-process-output based approach in educational effectiveness research (Creemers and Scheerens, 1994). The system approach in their study instead seems to put the educations in the centre, as the inputs are considered to be students´ background including personal and financial resources, the context is related to educational contexts of schools and socio-economic context, the process or throughput are considered to be the factors within the school, and the outputs are students´ achievements and educational attainment.

Input factors are considered as the input for the students in the teaching and learning process environment. The input consisting of all kinds of variables related to the structure of program e.g. the electronic and electrical engineering curricula and courses/modules outlines and teaching materials. Besides that, the institutional context of the program structure is also considered as an important input factor, here in the case studies at AAU represented by the Danish qualifications framework and UTM represented by the Graduate Attributes and Professional Competencies.

The throughput factors in the case studies at UTM are the students activities in active learning environments whereby in the case studies at AAU are analyzed in two sections related to i) the student directed team work and ii) the influence by teachers in the facilitation of students´ project work by questioning students, discussions at group/class meetings as well as feedback to students on their writings. These teacher behavioural factors are positively related with student's achievement (Brophy and Good, 1986).

In a systemic approach, output factors of teaching and learning process refer to the students´ learning outcomes such as basic skills, other cognitive outcomes and non-cognitive measures (Centra and Potter, 1980) or abilities, knowledge, skills and competences (Rompelman and de Graaff, 2006). In this thesis, it is assumed that students´ project report can be analysed as representations of students learning outcomes. In the case studies at UTM, the researcher has analysed nine students´ reports. In the case studies at AAU on the other hand six reports have been analysed, two from each module, to exemplify the progression in the integration of sustainability in the first semester of study (P0 and P1) and in the second semester of study (P2).

Based on the literature the researcher leans towards the systems approach introduced by Rompelman and de Graaff (2006) as the focus is on the educational practice, also inspired by Creemers and Scheerens (1994) to take into consideration the broader institutional input factors. Two main data collection techniques were used for this analysis: document analysis and interview sessions. First of all, documented evidence such as electronic and electrical engineering curricula, course/module outlines, students´ assignments and students´ project reports was collected. The keywords related to ESD (i.e. sustainable development, sustainability, environmental perspective, social/culture perspectives, sustainable technology, and green technology) were used to identify the manifestation of the integration in the document analysis. Secondly, four interviews were planned and carried out with teachers, coordinators of the modules and ESD experts. The interview sessions were structured to identify intangible forms of integration yet not documented and beyond what could be read in the available documents.

6.7 Results and discussions from case studies in UTM

Input factors

A. Documented in accreditation requirements and recognition purposes

Engineering programs in Malaysia generally are restricted by guidelines and policies for accreditation. Engineering Accreditation Council Malaysia (EAC) is the leading accreditation body that accredits local engineering programs and conduct recognition of foreign engineering programs. The EAC stands on behalf of five main stakeholders from academia and industries. The stakeholders consist of Board of Engineers Malaysia (BEM), The Institution of Engineer Malaysia (IEM), Malaysian Qualification Agency (MQA), Jabatan Perkhidmatan Awam (JPA) and Industry Employers from practicing professionals.

The accreditation requirements and recognition criteria of the EAC are the most influential input factors contributing to the integration of sustainability in engineering curricula in Malaysia. Under EAC, Malaysian engineering programs are also bounded to the guidelines and policies outlined by the International Engineering Alliance (IEA). The IEA stated in the Graduate Attributes and Professional Competencies in 2009 that, in the context of sustainability, graduate engineers are expected to:

i) Design/develop solutions – Design solutions for complex engineering problems and design systems, components or processes that meet the specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.

ii) The engineer and society – Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice.

iii) Environment and Sustainability – Understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development.

iv) Ethics –Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.

B. Written in course learning outcomes (learning objectives) and in course summary

In general, the aims of an engineering course are outlined by the course learning outcomes. The course summary on other hand is written to introduce to the prospective students the contents of the course. The course summary is organized to be aligned with the course learning outcomes. In this study, the learning outcomes and the course summary for all cases are explicitly integrating the elements of sustainability i.e. engineering ethics. This second input factor can be expressed in many ways in learning outcomes. In this chapter, the learning outcomes for learning sustainability can be expressed in two ways. First, the elements of sustainability could be embedded in the existing learning objectives, where the elements of sustainability are contextualized into the core contents and discipline. Second, the elements of sustainability could also be separate learning objective(s) from the core contents. The following discussions apply:

In the first case, the elements of sustainability are integrated in all learning objectives. The elements such as fundamental concepts and principles of sustainability, roles of engineers and engineering ethics, and the empowerment of engineer are integrated wisely in the context of the course. Another example, in the third case the elements of sustainability are contextualized into the field of construction engineering. The fundamental concepts and principles of sustainability – a general discourse about sustainability is the introduction part of the course, followed by understanding and applying sustainability tools and policies that are important for construction engineering, and ended with assessing the engineering solution into the sustainability perspectives.

Different with the first and the third cases, in the second case the topics that are related to sustainability are separated from the other core topics (core contents). For example, the core topics for this course are primarily focused on the fundamental principles of civil engineering as a practice and profession. The discourse about the principles and concepts of sustainability is as an isolated sub-topic from the main topics. However, the perspectives of civil engineering profession and the practices are reflected in this specific discourse on sustainability.

C. Formulated in a problem or project proposal

The third input factor is the problem or project proposals. The proposals mainly are designed and aligned with the course learning outcomes and they provide a platform for an active learning environment. There are four cases presented in this discussion with each of the proposals giving different learning experiences and competencies.

In the first case, the teacher provided students with a real problem related to sustainability. The students have to find solutions on the high water consumption amongst university students living in campus. The problem was formulated to bring the issues into the local context or the community of university students. Therefore, sustainability could not only perceive as the issues that are distant and unrelated to their daily life but could also perceive as issues that are very closely related to them.

In the second case, the teacher proposed a project for enhancing the awareness of sustainability amongst engineering students in Faculty of Civil Engineering. The project was entirely organized by the students in this course and the participation was open to all civil engineering students. The project was called "sustainability week", where the project was executed for a week. The project aimed not only to educate the visitors of the sustainability week but also to create an active learning environment where the organizers and participants exchange their perspectives and thoughts on the issues related to sustainability.

In the third case, the teacher initiated the project by proposing to the engineering students to conduct a one-day seminar for students in technical schools or polytechnic institutions. This project aims for students to foster their understanding of fundamental concepts and principles of sustainability and they should be able to contextualize the concepts into their perspectives as a future engineer and deliver the principles to the younger generations. The students also have opportunities to gain their soft skills or generic competencies i.e. communication skills.

In the sixth case, initially the project aims to integrate elements of sustainability in a competition method for only students in this course but later the competition was opened to the national level. With a competition theme of Deep Water Floating, the participants have to build a model of a structure that floats and is capable to hold the heaviest weight, using the least budget and employs sustainable materials. The participants were also expected to apply the basic principles for offshore structures and employ the holistic approach in their model.

Throughput

A. Student activities in an active learning environment

In addition to the implementation of a traditional teaching technique i.e. mass lecture, the cases depicted in Table 6.3 also are implemented in a student-centred learning environment. In practices, most engineering teachers combine the student-centred approach with the traditional method. Examples of sustainability incorporation in student's activities implemented in the cases are presented in nine activities as listed below:

i. Peer teaching on topics related to sustainability

In the first case, each of the students participated in peer teaching. The students were either assigned by the teacher or volunteered to learn a particular topic of sustainability, a weak (could be more than one week) before the peer teaching activities. They were asked to independently learn and master the topic. For instance, for three sustainability topics, students would be asked to form three groups (group A, B and C). Each of the group will master one topic. In the first round of peer teaching, the students have to teach amongst them based on what they understand on that particular topic. In that process, the students will discuss, argue and question every time they face difference of perspectives and understanding. Later in the second round, the groups will be reformed, and most of them will have new group members (Mixed of the members from group A, B and C). As a jigsaw concept of peer teaching was applied, every student not only had a chance to share their knowledge and understanding on their mastered topics. They also learned new topics from their peer.

In the sixth case, students also participated in peer teaching. The peer teaching practice in this case however enabled them to have full liberty in choosing topics. They have to choose topics that are not part of their syllabus. So that the students have a wider perspectives on sustainability and they have opportunities to explore a variety of real world sustainability issues in the classes. In a small group, students present their findings with their own creativity including additional materials such as poster and notes.

ii. Visiting industrial plants, industries or construction sites that implement sustainability principles, standards and regulations

Day trips or two-day trips to industrial plants or constructions sites is one of the teaching methods that could create an active learning environment. This effort can be seen in the first case where each group has to plan their visit to a place where sustainability principles or regulations related to sustainability are employed. In their visits, the students can experience on how sustainability principles are applied in the work places. The students can also have opportunities to have face-to-face discussion with engineers. For that purpose, the students have to prepare a set of questions for a discussion session with the practitioners. The students are fully supervised by the teacher in the preparation of the questions; so that the topic of the discussions is aligned with the main objectives of the visits, as well as achieving the course learning objectives.

iii. Virtual meeting and forum on thematic topic related to sustainability and engineering education

One of the methods of active learning that has been implemented in UTM is by conducting a virtual meeting and forum on online systems such as UTM e-learning system. For instance, in the first case students can actively participate in online forums, where issues of sustainability are discussed virtually. Students have opportunities to raise any issues that are problematic to understand or good for stimulating a debate.

This activity provides a platform for students to express their perspectives toward the issues and the students have shown their capability to respond constructively rather than creating a conflict.

iv. Sustainability talks as community services at technical schools and polytechnic institutions

Unlike mostly practiced sustainability talks where experts or teachers give the talks; this kind of sustainability talks are conducted as community services by the engineering students to the pupils at technical school and polytechnic institutions. For example, in the third case students were planning a one-day talk about sustainability and future engineer at selected technical schools or polytechnic institutions. They were responsible to give speeches, to coordinate activities and to provide informative materials for the whole day. In addition to their work, they also have to provide a set of questionnaires for the participants, for them to give feedbacks either in the aspects of contents or activities. These community services were planned by a small group of five students of the course Sustainability & Environmental Management in Construction.

v. Problem based learning on thematic topic related to sustainability; a group work aimed at a technical paper for conference

A problem based learning approach on thematic topics related to sustainability for a course named Sustainability and Environmental Management in Construction (third case) has created an active learning environment, where students have to be involved in every process of problem identification and analysis, providing sufficient literature and reporting. The students also have to write their original thought of the topic in the form of an article and they have to present their article. Besides gaining knowledge in sustainability and understanding its relation to the engineering fields, the students are also experiencing the same process of publishing a conference article.

vi. Cooperative learning based on case studies related to sustainability in civil engineering and offshore structures

In case two and case six, the students actively participated in discussions based on the given case studies. The case studies are usually taken from the real world engineering activities either from global cases or local cases. In the discussions, students individually expressed their opinions and responses in big groups and also reflected on the case studies as a form of appreciation of sustainability.

vii. Cooperative learning and cooperative problem based learning on thematic real problems related to sustainability for Introduction to Engineering course.

In practice, to implement the theme into the classroom, students were provided with real problems that occurred in their daily lives. For this course, mentioned in case one, cooperative problem based learning was implemented into the classroom. A theme such as “Minimizing water consumption” had brought students to identify and analyse the real problems within their circle. They started with their own water consumption, and then went further to friends and then to the whole campus.

viii. A competition on sustainability in engineering education

In case six, a national competition called Deep Water Floating was one of the learning methods applied for Offshore Structures students. They worked in groups to propose a structure by considering three main aspects; material consumption, functionality, and cost. In another case, a competition for reducing water consumptions amongst university students has been conducted for chemical engineering students. This group project ended with tangible solutions and presented in a form of a competition. The competition (case one) was created as a platform for students to learn from their peers. The students also went through a process of defending their project in evaluation sessions with internal and external examiners.

ix. Sustainability weeks for a whole university and engineering students

For Civil Engineering Fundamentals students, they organized a program called Sustainable Living Weeks and Civil engineering as mentioned in case eight. The students worked in groups to contribute to the program by preparing their booths with posters, flyers, pictures and videos. Each group has been devoted to a specific theme, such as sustainable wall and sustainable roof system in which holistic perspective were demonstrated in their works

Output

A. Students´ reports from case two

The reports were prepared by the students for the visits to the actual construction sites. The aims are to present their findings on the construction activities and their impact towards environment and social. Two students´ reports were randomly selected as samples to exemplify the incorporation of sustainability in the learning outputs. Each report was prepared by a group of students on different construction sites.

The first report explains mostly the negative impacts of construction activities towards the environmental and social dimensions. By stating that construction activities are the major contributor to resources depletion, the students were also giving examples of the negative impacts to the environment such as noise pollutions, construction wastes, sedimentation and site clearance. The report also shows evidence on the ability of students to relate the construction impacts on the environment which are causing inconvenience to the surrounding community and natural habitats. Students also reflected the research outcomes in the context of construction management where practicalities issues are put into their considerations. From the report, the students have shown their ability to conduct an empirical research with structured interview sessions and observation as parts of their research methodology. These activities prove that students do not only have the ability to reflect on the impacts of construction activities into the perspectives of environment and social but that they are also aware of the importance of those aspects in conducting research.

The second report is written to report on the visits at two construction sites. The students showed their ability to relate the construction activities with environment pollutions. They also reflected the construction activities into the context of construction management and highlights problems occurred on the construction sites. However, the report shows that the students are only focusing on the environment perspectives even though the impacts could contribute to the surrounding social and economic problems. The report is also an evidence of the ability of students to self-study on the topic of construction management in the process of preparing the report.

B. Students´ reports from case three

The following discussions are the results from analysing three students´ reports on their community services at technical schools and polytechnic institutions. The objectives are to report their activities (mentioned in the earlier sub chapter) and the results from the pupils' feedbacks on the community services.

In the first report, students highlight the environmental impacts of development activities in the community service. They focused on the impacts such as urban air quality, river quality, deforestations, household wastes and hazardous wastes. The students outlined the importance of sustainable development by presenting the three main pillars which are the social needs, environmental protection and economic development. In the report, the students stated that the aims of the community service are to:

i. *Promote understanding of sustainable development concepts*
ii. *Encourage critical reflection and decision making that is reflected in persona lifestyles*
iii. *Engage active participation in sustainable development programs*
iv. *Promote understanding of the environmental protection requirements*
v. *Give understanding on the importance of conservation of natural resources*

The students also provided findings on the effectiveness of the program based on the pupils´ feedbacks.

In the second report, it shows that the students promoted or educated the pupils on the concepts of sustainable development by presenting the fundamental concepts of sustainable development and giving some examples on how the concepts can be implemented into their student life. The contents of the program are as the followings:

i. *The definition of sustainable development*
ii. *The government acts on sustainable development*
iii. *The fundamental concepts of sustainable development*
iv. *The 21st Agenda*
v. *The green house effects*
vi. *Ecological footprint*
vii. *The relation of sustainable development into student daily life*

In the program, a set of attitude test has been distributed amongst students to assess their attitudes towards the recycle, reuse and reduce paradigm.

In the third report, the community service aims to i) identify pupils´ understanding on sustainable development, ii) share the knowledge of sustainable development and iii) reflect the outcomes. By these objectives, the students focused the talk to increase awareness amongst pupils on sustainable development and explain the fundamental concepts of sustainable development, issues of global warming, transportation, green area, recycle and the contributions that pupils can provide. The report is also an evidence of self-reflections amongst the students in the context of sustainability where they were sharing their experiences working in the engineering companies and dealing with issues related to sustainability.

C. Students´ reports from case 4

The reports were prepared by students to show their understanding of the concept of sustainability and responding to the given topic. There are three reports that have been analysed and served as examples of the learning output. The first report is about environmental conflict at construction sites, the second report is written to present policies and actual implementation on the issue of energy and the third report discusses sustainable landfill.

In the first report, the students show their understanding by explicitly stating the importance of development in the perspectives to provide quality of life and better infrastructure as well as in the economy. The students also showed their stand on the goal to balance between development and environment, where development is important as well as environmental protection. In the context of environmental management, the report shows the ability of students to reflect the problems that occurred by highlighting the causes which are attitudes of the person/agencies that are obligated for the development and the construction activities itself. The reports also show that the students are able to relate clearly the effects of development to i) the mangrove in the neighbourhood, ii) aquatic life and iii) local community which includes issues related to quality of life, water, health, and economy. In the final part of the report, the student proposed to reinforce the existing regulations and policies as the solutions for the problems. The proposed solutions are (by researcher understanding) not able to overcome the mentioned problems without considering the existing technology or system that is not sustainable. However, the proposed solutions are evidences of the capability of students to reflect holistically the principles and the concepts of sustainability without focusing solely on economy or environment.

The second report shows students' understanding of the importance of saving the energy and the depletion of resources resulted from the energy production activities. In the context of energy saving, the students relate between the global issues and the local issues such as the depletion of local resources and its impacts on the environment. However, most of the discussions are about saving energy in the perspectives of economy e.g. saving cost and saving bills. There were no efforts to propose solutions in holistic way and practical.
The third report shows that the students draw the connections from human activities toward the environment and social aspects. By stating that most of problems merged from human activities

are due to lack of management in environment, the students proposed several solutions that's highlights the sustainability aspects include financial and technical abilities, minimizing the negative impacts on environment and social, and educating the households.

6.8 Results and discussions from case studies in AAU

In the following paragraphs, the researcher will present three salient "factors" to analyse the way sustainability has been integrated in the programmes of Electronics and IT. Together with the Danish qualification framework, the written statements in the curriculum related to the three project modules in focus, constitutes the input factors. As throughput factors we consider formulation of objectives/requirements, facilitation and team activities during the project period, and finally as output factor, we have considered students learning outcomes represented by project reports.

Input factors

A. *Documented in Danish qualifications framework*

The Danish qualifications framework aims to make the degree structure in Denmark for higher education programs nationally and internationally clarified and transparent. The qualifications framework also describes the desired outcomes and competencies in such a way that it can steer curricula planning. The importance of the qualifications framework is underlined by the inclusion of stakeholders representing universities, non-university programs, students, Danish Evaluation Institute, Danish Centre for Assessment of Foreign Qualifications and employers.

In general, the Danish qualification framework was established based on a model that encompasses i) Competency profiles, ii) Competency goals and iii) Formal aspects. The competence profiles are provided to specify the variety of competencies needed and three types of competencies are defined being i) intellectual, ii) professional and academic and iii) practical.

Intellectual competencies point to general process competencies for intellectual development; being neither specified as disciplinary nor program oriented, e.g. communications skills, self-learning, analytical and abstract thinking (The Danish Bologna follow up group's QF working party, 2003). By this time on the Bachelor level, students have to be able to identify their own learning needs and organise their own learning in different learning environments (Ministry for Science, Technology and Innovation, 2009). This goes well together with PBL and its emphasis on exemplary learning as well as meta-learning.

On the contrary professional and academic competencies are related to a specific discipline or programmes, whereas practical competencies are specifically aimed to the fulfilment of job functions e.g. professional ethics and responsibility (The Danish Bologna follow up group's QF working party, 2003). Even at the bachelor level, the qualification framework state that engineering students must be able to handle complex and development-oriented situations in study or work contexts, and furthermore that they must be able to independently participate in discipline-specific as well as interdisciplinary collaboration with a professional approach (Ministry for Science, Technology and Innovation, 2009). Taking the increasing complexity of technological systems into considerations as well as the increasing focus on environmental management and corporate social responsibility in business, the qualification framework creates an important platform for integrating sustainability in engineering education.

B. Sustainability related learning objectives in the written curricula for the three modules

All though the Danish Qualification framework provides a platform for integrating sustainability it is not a premise for accreditation that sustainability is explicitly mentioned in the written curricula. This is however the case for the curricula for electronics in relation to the first year as shown in the analysis of the learning objectives, related to the following three project modules.

In the project module entitled Technological project work (P0), the overall objective enables students to describe and apply typical elements of a problem-based project, manage the learning process and provide reflections on this process. The relation to ESD is that the students should be enabled to describe the problem in a holistic perspective.

In the following project module, Basic Electronic System (P1), the course learning outcomes were constructed to provide students with knowledge, skills and competencies related to both electronic system and ESD. At the end of the course, students is expected to understand the basics of electronic systems, but this also includes interaction with the outside world and identification of relevant contextual perspectives including technological as well as societal aspects. The students is also expected to identify requirements for technical solutions based on these contextual perspectives, and furthermore show their ability to manage a project include planning, structuring, implementation and evaluation. In addition, it is stressed that the students have to take point of departure in a problem having societal or vocational relevance.

The last project module on the first year, Dynamic Electronic Systems (P2) is offered at the second semester for electronic engineering students. The module is, besides progress in the understanding of electronic systems, specifically designed to integrate knowledge related to the field of Science, Technology and Society (STS) supported by a subject at the first semester. Students have to obtain adequate skills to analyse and solve a technical-scientific problem taking technological, environmental and also social aspects into consideration in the problem analysis as well as in the assessment of the social and environmental consequences of the proposed solution. Specifically user involvement, stakeholder analysis and analysis of environment regulations are mentioned as areas of interest. In the process of solving the problem, students also have to sharpen their abilities to construct comprehensive models to be used in design, implementation and test of an overall system to assure that the requirements and the desired specifications are met.

C. Project proposals

As a third input factor, the facilitators provide students with project proposals designed to the learning objectives in the curricula. It is however possible for students to contribute themselves with a project proposal. Project proposals outline the problem-field and the related possibilities to contextualise and develop technical competence within this field. In most practices, the project proposals are constructed in an open way, so the students themselves are formulating the initiating problem and problem formulation.

This input factor could be the most vital element for the efforts to provide education about sustainability in electronic engineering education, as previously highlighted in the introduction, sustainability could in fact be an overarching theme and the project proposals could be developed to capture different aspects of sustainability in relation to the disciplinary field of work. For instance, there was a P1 project, executed by the second semester of electronics engineering students and the project was designed to deal with pupils with disabilities.

In the electronic and IT programme, the proposal can be entirely funded by industries or companies, or the proposal can be prepared specifically for education purposes. Teachers will normally prepare the proposal and present it among a committee or peers including all teaching staff at the semester. The approved proposal will be collected and offered to the students to choose. The students are thereby occasionally triggered with a proposal in relation to sustainability.

Throughput factors

A. *Project activities*

Throughput factors in terms of project activities have considerable impact on the integration of sustainability in electronic engineering curriculum to maintain the momentum and manifest ESD as a process and not only an input or outputs of engineering projects. The study has identified three possible activities along the process of developing the project or finding a solution that integrates sustainability, that is i) the identification and analysis of problems, ii) product design and test iii) product evaluation.

Early in the process of identifying problems, the students' start out with an open problem and the further analysis of the problem include an explicit focus on the social as well as environmental aspects of the problem. Some of the problems, either proposed by the teacher or students, demand at least a site visit and discussions with stakeholders. During such processes, students will have opportunities to identify related issues regarding the technical problems as well as the related non-technical social and environmental aspects. They also have to develop instruments for collecting data such as interview guidelines and questions for interview sessions with the stakeholders; and in the design of these instruments an explicit focus on sustainability is evident.

Later in the process of designing the possible solution to the now well-defined problem, a specification of the demands to the products can be made based on the conclusion of the problem analysis. All though students often delimit the project by a narrow problem formulation calling for pure technical developments – the students then are aware of the more contextual factors coming into play in real life product development, where departments of environmental and/or health and safety often are involved. In that way they learn how to be specialist in a team and at the same time have enough inter-disciplinary knowledge from cross-departmental collaboration.

In the same line of reasoning, students are, in the last part of the project, asked to make overall assessment of the products impacts on environment as well as society at large. In this phase more strategic management tools such as SWOT analysis (assessing the strengths, weaknesses, opportunities and threats) or screening tools (e.g. in relation to environmental assessments) often are in play.

B. *Facilitation*

One of the essential features of PBL is that the students are at the centre of the learning process, and have to take responsibility for their own learning. The teacher is not telling students what to do, but instead guide them along the process of learning with reference to the learning objectives. Unlike the traditional methods of learning, where teachers usually has full control of learning process and contents, teachers in a PBL environment takes the role as facilitator (Kolmos et al., 2008).

One of the tasks of the facilitator in a PBL environment is to keep students on track in their projects, so they progress in alignment with the intended learning outcomes. Therefore, for the facilitator to make sure that sustainability is integrated in the project work, there will have to be a clear reference to the curriculum. On the other hand, if the learning objectives do not point to the integration of sustainability, this sometimes unintentionally occurs in the process, due to nature of the chosen problem, which is closely related to the field of interest of students. Based on the learning objectives or student's interest, the facilitator will provide some insight and maybe put some more emphasis on sustainability in the project facilitation.

However, the integration of sustainability challenge the facilitators to have a clear understanding of the subject and as one of the criteria's for accreditation of HE in Denmark is that the teaching has to be research based, this calls for an inter-disciplinary team of teachers. In this specific case, teachers from the Department of Development and Planning contribute with researchers working in the field of sustainability science and Science, Technology and Society (STS). These researchers are involved in a course module at the first semester, and co-supervise the groups in the project module in the second semester.

In the case where sustainability is integrated in the project modules, the facilitators play important roles in motivating the students and help students to open up to other lines of thinking. This sometimes happens, when the facilitators question the conditions of the project or provide suggestions to integrate economic, social or environmental concerns. This often leads to discussions of the role of sustainability in the project and the ways to integrate sustainability in the project without compensating technical competences. This directive approach (with reference to the learning objectives in the study regulations) combined with a collaborative approach is very much depended on students´ motivation, performances and ability to achieve the course learning objectives.

In other cases, students had opportunities to meet external personnel such as engineers and managers from companies to make a network and collaboration on developing their projects. To get in contact with various stakeholders and meet with the target groups or users of the products was a great experience for students to understand their problems and to develop their project. In this way students also have the opportunity to experience, that sustainability plays a role in real life innovation of electronic products.

Output factors

A. Students' reports in P0

The analysis of two P0 reports shows that the students have reached the intended learning objectives in relation to PBL and basic knowledge in the field of electronics. The students all had the same project proposal, where they had to develop a robot using LEGO mindstorms® that can cope with some challenges put forward by the facilitators e.g. carrying items or follow a predefined route. Being able to build something and compete with each other motivated the groups. However, due to the very fixed technical challenge, it is very hard to find any evidence that the students in fact have had a holistic perspective on their project as intended in the learning objectives.

B. Students' reports in P1

In the P1 project reports, sustainability solutions are the target, but at the same time reflections or relations to sustainability are not explicit in the report.

In one project, students proposed stimulation tools for pupils with sight and hearing disabilities. Due to pupils´ disabilities, it is vital for the tools to have cardinal features such as interaction and strong responses to the user. The strong responses could be in the form of light, sound and vibration. In addition to that the students have to present ideas of activities that combine physical activity with social elements and learning to stimulate the pupils at Centre for Deaf Blindness and Hearing Loss, CDH. The project also included i) A study of possibilities for stimulating sight and hearing disabilities based on interviews with employees at CDH and selection of ideas for project development, ii) Preparation of technical specifications for the system iii) Design and construction of a laboratory model, and iv) A testing and assessment product.

The other project considers assistive technology for people with sight disabilities in order for them to manage everyday life. In the project, the students made interviews with representatives from the Danish society for the sight disabled, to point to the most important challenges in the everyday life of blind people, get an overview of the assistive tool already at hand and what demand does this organisation has for assistive technology. Based on that, an interface instrument was developed to help blind people in their use of public transport.

By focusing on the assistive technology, these two projects can be considered as social responsible projects. Furthermore, the real life social problem is carefully analysed by involving the target group and using their input for product design. However, there is no explicit reference to aspects of economic or environmental sustainability; and there is no real trace of sustainability in the approach to the problem analysis and problem solving.

C. Students' reports in P2

Students report at P2 is clearly influenced by the increased and more specific integration of sustainability in the learning objectives and the presence of a co-supervisor with special attention and competences in relation to STS and ESD.

In one of the reports social sustainability play a role in the purpose of the project that is to improve traffic safety by intelligent headphones identifying and amplifying signals of danger. Other projects working with intelligent headphones have instead been targeted at the quality of working environments by reducing noise problems. This is an example of the same product type and basically the same technical learning outcomes related to different types of problems related to different contexts. In the analysis of traffic safety problems the students drew open statistics of traffic accidents and they developed a survey instrument to investigate different types of distraction problems in traffic. Furthermore students measured the amount of noise in traffic and developed a prototype. In the final part of the project, they made overall assessments of the environmental impact from the hardware and estimated the market price.

The other report analysed from P2 have the objective of making a small satellite, which can be used for educational purposes at high school level. Interviews were made with high school teachers and pupils in order to develop an educational set-up around the satellite. Interestingly, student estimated the environmental impact from the satellites as a part of their problem analysis – and thereby before they develop their prototype. They calculated the CO2 emissions to send up a satellite and found that the emission of sending up one is approx. equal to 1.25 km of car driving. Besides environmental regulation has also been discussed referring to the WEEE directive (on Waste from electrical and electronic equipment) and the RoHS directive (Restriction of Hazardous Substances). Based on these and more technical consideration a prototype of a satellite was developed.

6.9 Conclusion – Inputs to design a framework: Managing sustainability competencies and course planning

Following the guidance of the accreditation bodies, engineering education at UTM has gradually incorporated sustainability in the curricula. The accreditation bodies, especially for Malaysian universities, have driven the transformation of engineering education and have shown its importance in developing education for sustainability. It became evident that accreditation bodies have to work side by side with universities in preparing guidelines for developing engineering programs and benchmarking the attributes for engineering graduates, so that the incorporation of sustainability in engineering education is not only perceived as conceptually acceptable but also applicable in practices.

Even though the qualification framework creates an important platform for arguing that sustainability should play a role in higher education, in AAU it is not a criterion for accreditation that sustainability is explicitly addressed in the curricula. In a PBL environment this is however crucial, as the learning objectives in the curricula is the frame of reference when guiding students in their learning process. However, bottom up initiatives are also important drives e.g. staff proposing projects with sustainability focus or students choosing to incorporate sustainability in their projects.

The results from this research phase have shown three salient factors, the input, throughput and output factors, of the incorporation of sustainability in engineering curriculum. It has shown that in practice sustainability has been incorporated into the curriculum based on the understanding of the designers/teachers on the concepts of sustainability and their interpretation of sustainability into the contexts/disciplines. It has also been shown that the strategies for the incorporation of sustainability in course planning depend on learning objectives and other components. Due to these scenarios, the strategies vary from one practice to another. In the case of UTM for instance, one of the courses has incorporated sustainability in the form of competition which is successful for that particular course and might not work very well if the same approach was adopted for other courses. Therefore, it is important for course designers/teachers to have a guideline e.g. clearly defined sustainability competencies, structured learning methods and learning activities, so that the learning objectives are achieved.

However, sustainability cannot be prescribed – it has to be lived, and as such be a part of the project activities and facilitation. Interviews with staff together with analysis of students report point to the conclusion that students do need to be facilitated to maintain the focus on sustainability and at the same time find a way to cope with this relatively complex subject in relation to a specific context without compensating core technical competences. Choosing sustainability in relation to the problem field e.g. by assistive technology for hearing disabled, is one way to incorporate sustainability, but this does not necessarily follow a comprehensive and holistic perspective in the design and implementation of the product.

On the other hand the ability to make overall assessments of the environmental, economic and social impacts from a technology should be developed at some time in the curricula, and here the strategy at Aalborg University has been to make sure that co-supervision is provided in the field of STS and ESD. Due to the strong collaboration in the supervisorial team, this might also be an indirect training of staff and raise the awareness of sustainability in research environments where this is not considered as the core discipline.

Sustainability has to be included and the aims or goals must be aligned in all three factors therefore the sustainability can be effectively addressed along with the teaching and learning process. The cases have shown that the sustainability is partly in the written learning objectives, dedicatedly discourse in the project activities or facilitation and documented in the project reports. However, there is still a room for improvement where the alignment of the three factors needs to be a part of the overall assessments. Therefore, the teachers as well as the students have opportunities to reflect and make improvements in any part of the learning process that insufficiently address sustainability. The researcher has also found out that even though students showed their abilities to reflect their projects in the perspective of sustainability which is commonly documented as a part of the project background and end-of-pipe analyses of project, there was a lack of reflection on sustainability perspective along the process of project development or realization.

Nevertheless, the case-example from both universities shows that, it is in fact possible to incorporate sustainability without compensating technical and engineering competencies as the core contents. This is however (in the case of AAU) due to a very structured project model, where students gradually work from an initiating and very open problem, through a process analysis phase, whereas they have gained a comprehensive understanding of the problem to narrow this problem to a technical problem to be solved, but still being aware of the limitation of their technical perspectives in a business as well as in a broader societal context. Engineers are not necessarily to become environmental managers or sustainability scientists; but they have to know how to bridge and collaborate inter-disciplinarily in their future profession in order to design sustainable sound solutions.

The results from this research phase also have provided important findings in the effort of the researcher to design a framework to incorporate sustainability in engineering curricula. The final design of the framework for course planning is explained in Chapter 9 entitled “A framework for incorporating sustainability in engineering curricula”.

6.10 References

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Chapter 7

Phase three: Evaluating course effectiveness

7.1. Introduction

This is a chapter to present results of the research phase three, which is the final research phase for the cycle of analysis, design and develop before it proceeds to the cycle of implementation and evaluation. The discussions of the results are based on the three cases, which are Case A, Case B and Case C, taken from the selected engineering courses offered at UTM. These three cases have been evaluated for its effectiveness in terms of knowledge, skills, and attitudes towards sustainability where the course learning objectives and students´ learning outcomes are part of the indicators. The following Figure 7.1 depicts the flow of the discussions in this chapter.

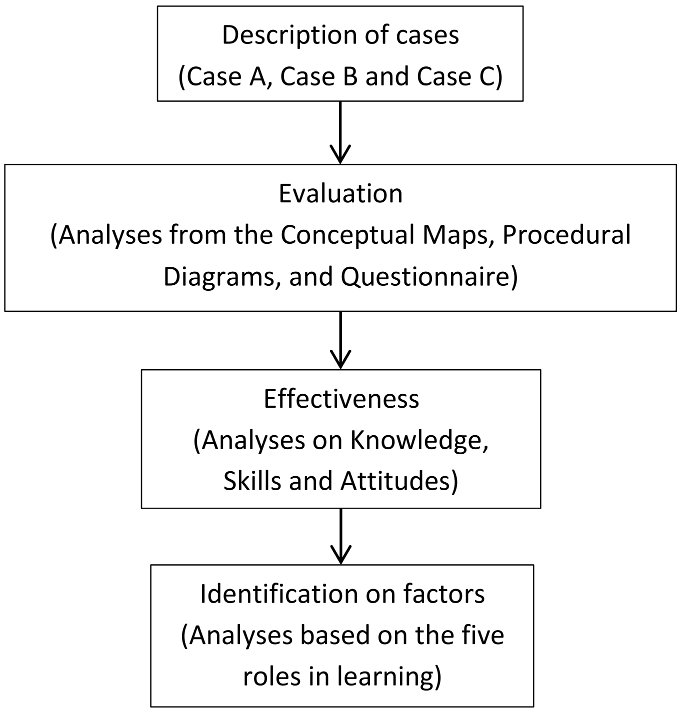


Figure 7.1 The paths of presentations for phase 3

7.2. Description of the cases

Besides of its main objective to evaluate effectiveness of sustainability incorporation, the outcomes of the phase three also contribute to understand the effects of curriculum e.g. course structures, teaching strategies, and to refine the design framework to incorporate sustainability. The data from this phase indicated to what extend (will be presented in the following discussion) the design of curriculum affects the students learning outcomes. It also will be further discussed by reflecting the data and the teaching practices into course planning perspectives. In the previous phase (see phase 2), seven engineering courses that integrate Sustainability have been studied in-depth on the curriculum design and its implementations. Thus, the selection of samples in phase three depends on the samples that had been used for the previous phase. However the number of participations for this study decreases to four engineering courses due to the availability of the teachers and the courses on that particular semester. All the participated courses (the samples) are offered by Universiti Teknologi Malaysia from two engineering faculties, Faculty of Chemical Engineering and Faculty of Civil Engineering.

In this chapter, the researcher presents the evaluation results from three engineering courses. The remaining engineering course was uncompleted due to insufficient data from the teacher.

Description of Case A

Course title: Introduction to Engineering

A 14-week engineering course is designed to introduce first year engineering students to engineering and preparation on learning engineering. The course is aimed to give an overview of engineering, the professions and engineer in Malaysia context. Structured by five learning objectives, the course provides understanding on engineering and the roles and responsibilities in various aspects, provides understanding on basic engineering theories, inculcates team working, co-operative learning activities, communication skills, managing and interpersonal skills, and introduces sustainability.

Description of Case B

Course title: Sustainability & Environmental Management in Construction

The course emphasizes the understanding on the principles of Sustainable Development based on Agenda 21 and construction industry. The course also provides understanding on the role of engineer towards Sustainability including environmental issues e.g. water pollution and environmental regulations and legislation. In addition, the course offers understanding on application of sustainability principles in construction such as issues related to energy efficiency in building, construction waste, construction noise, biodiversity and various sustainability control and prevention method for construction.

Description of Case C

Course title: Plant Design

This fourth-year engineering course is designed to inculcate the principles and methodology of process design. The course mainly focuses on the key elements of process design including process creation/synthesis, process analysis, process evaluation and process optimization in generating safe, economic and environmental friendly processes. This course also instills various analysis methods such as equipment cost correlations and indices, and pinch analysis method to design maximum heat recovery network. In addition, the course inculcates team working skills and communication skills.

7.3. Course evaluation for the three cases

The evaluation process started by distributing the instruments to respondents where the instruments employ Conceptual Maps, Procedural Diagrams and self-rate procedure, and strongly agree/strongly disagree items. They responded to the instruments based on their expectation on to what extend students will achieve the learning objectives (for teachers) and responded on the achieved learning outcomes (for students). The respondents draw conceptual maps that represent the knowledge of sustainability and procedural diagrams that represent the sustainability skills. On other hand, the students´ attitudes towards sustainability are represented by numeral scores from strongly agree/strongly disagree items. In this research phase, there were three teachers (one for each case) and there were 16 engineering students for Case A and Case B, and 20 engineering students for Case C participating in the evaluation process. The instruments have been distributed at the end of the courses therefore the students´ learning outcomes are able to be measured.

In order to analyse the responses from all cases; the researcher has divided the analysis into several segments based on the type of data. First, this study will present the result from analysing the documented learning objectives. This is the process where the researcher uses the result as a benchmark to the provide knowledge by the teachers and the students´ learning outcomes. The purposes of benchmarking were to identify the differences between the plans and the practices, and to analyse the effect of the differences towards students learning outcomes.

Table 7.1 Detail of analysis process

Type of data	Analysis detail
Course learning objectives	i) Convert to conceptual maps ii) Code the concepts iii) Convert to index values iv) Indicate the provided knowledge
Concept maps	i) Code the concepts ii) Convert to index values iii) Indicate the provided knowledge
Procedural diagrams and self-rate procedures	i) Code the diagrams ii) Calculate the scores iii) Convert to index values

	iv)	Indicate the provided skills
Closed-ended questionnaire	i) ii) iii) iv)	Code the items Calculate the scores Convert to index values Indicate the expected attitudes

Second, the study will present the results from teachers´ feedback of the case. It will present the provided sustainability knowledge and skills as well as the teachers´ expectation of students´ attitudes towards sustainability. Third, the results of students´ concept maps, procedural diagrams and feedbacks are presented as the obtained sustainability knowledge, skills and attitudes.

7.3.1. Case A

Documented learning objectives

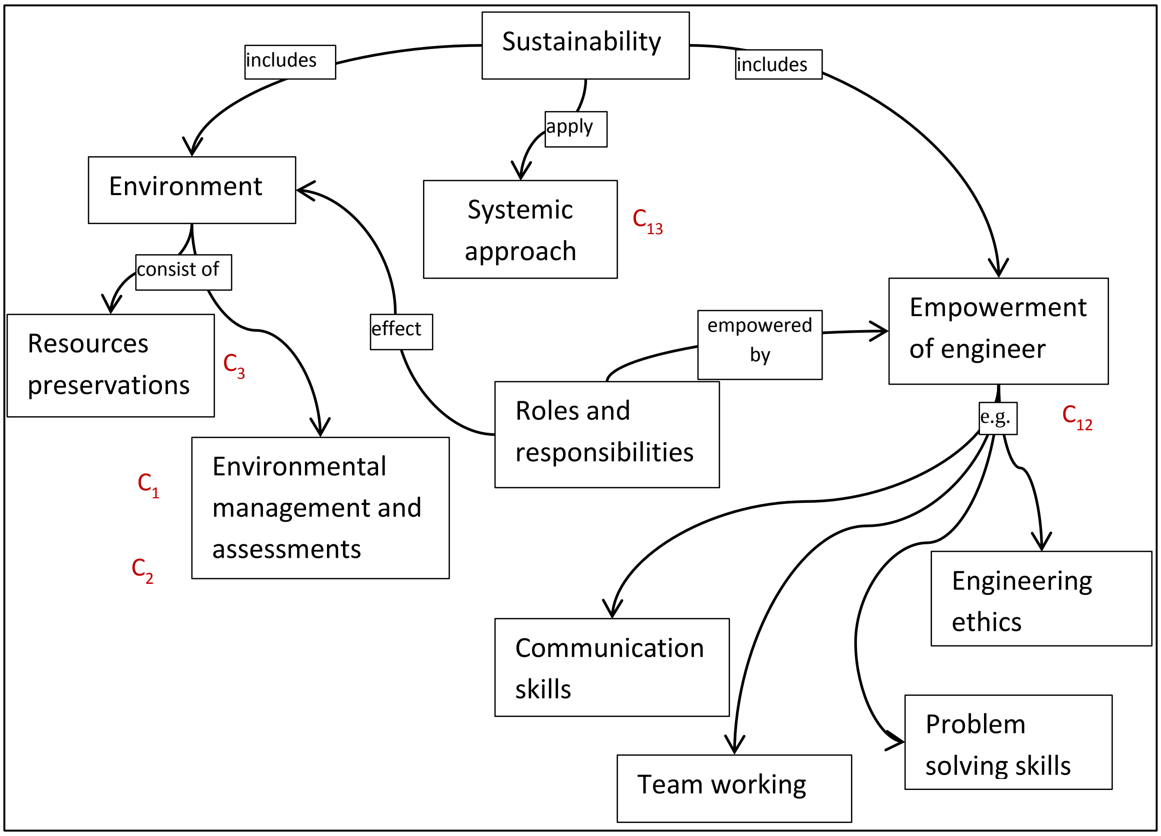


Figure 7.2 Concept maps for C1

Figure 7.2 depicts the concept map resulting from converting the documented learning objectives. The concept map is drawn based on the interpretation of the researcher on the topics of sustainability provided and written in the course outlines. It shows that, in context of learning the knowledge about sustainability, the course is focused on the aspect of environment and empowering the role of engineer. By applying systemic approaches, the course highlights resources preservations, environment management and assessments (aspect of environment) and instils engineering ethics, problem solving skills, team working, communication skills and engineer's roles & responsibilities.

Table 7.2 Index values for Case A

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Response	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0
Index of C_i (i=1-15)	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0

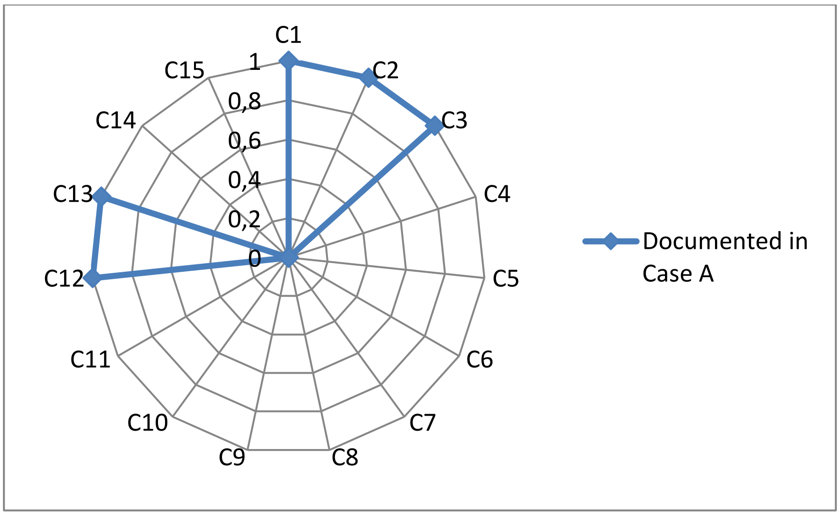


Figure 7.3 Sustainability knowledge documented in Case A

From the coded concept map, the data are converted to index values in Table 7.2. The table shows that C_1, C_2, C_3, C_{12} and C_{13} are valued as 1 and the other categories are valued as 0. From there, the documented sustainability knowledge in Case A can be presented as in Figure 7.3 where five of the categories are scored as 1. (Please refer appendix D for code of categories)

Teacher´s concept maps

The following figure shows the caption of a conceptual map (c-map) taken from respondent I3C1. The C-Map is marked with codes according to respective category. From the C-Map, it can be explained that Case A provides all elements of sustainability (except C_2 and C_8) as a part of learning and the students are expected to obtain the knowledge.

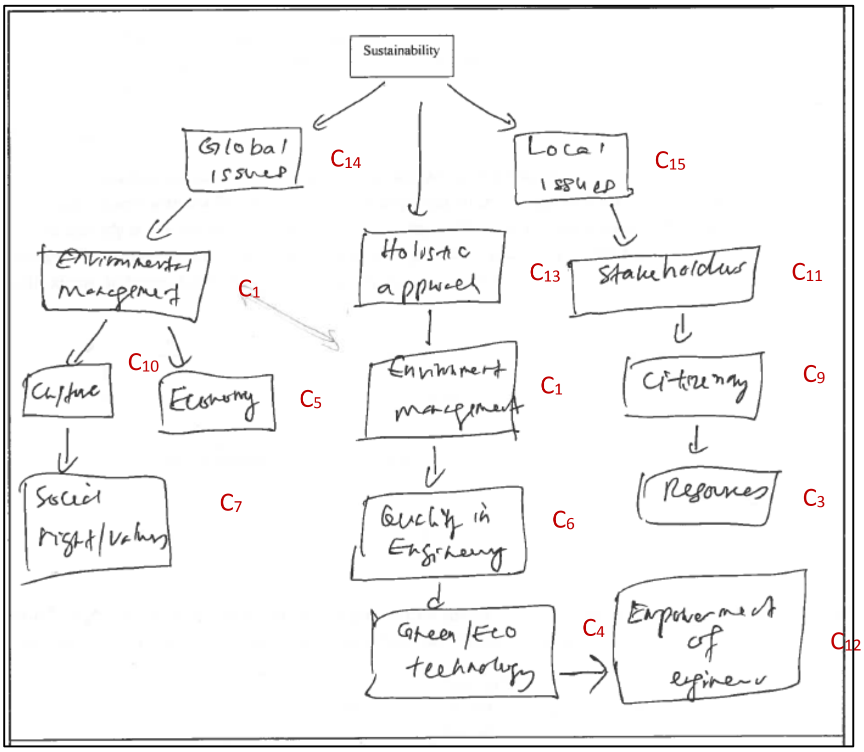


Figure 7.4 Conceptual maps drawn by teacher I3C1

Later, the coded concepts (or sub-concepts) from the c-map is sorted in Table 7.3. The table also depicts the index values of each category. Note that the index value (Index of C_i) is either 1, e.g. C_1 and C_2 or 0, e.g. C_8 according to its availability.

Table 7.3 Index value for each category (c-map from Case A)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Response	2	0	1	1	1	1	1	0	1	1	1	1	1	1	1
Index of C_i (i=1-15)	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1

The indicator shows that Case A provides sustainability knowledge on all categories except for two categories; environmental assessments (C_2) category and equity (C_8) category. The outcome is not aligned with the documented learning objectives. By comparing the indicator in Figure 7.2 and Figure 7.5, it shows that the teacher expects more than what are stated in the learning objectives.

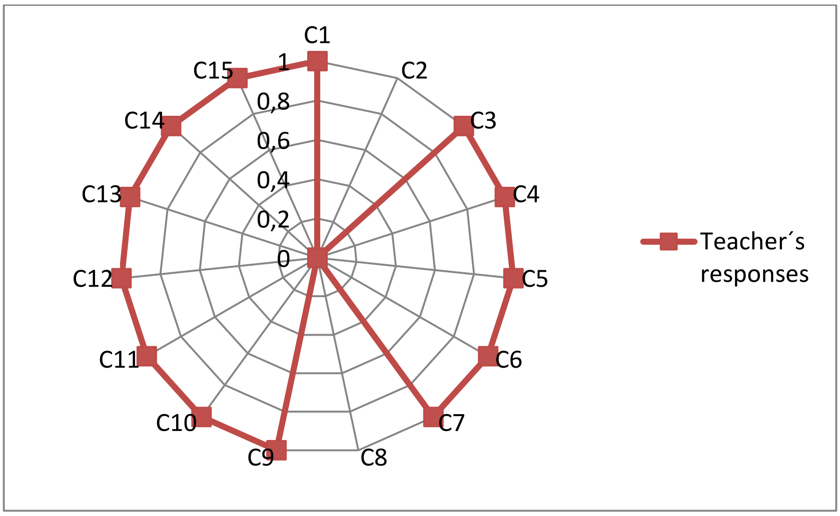


Figure 7.5 Sustainability knowledge provided in Case A

Teacher´s procedural diagrams

Based on the teacher´s responses, there is no diagram drawn in the Procedural Diagram and self-rate procedure (PD) for Case A. Therefore, this indicates that course A was designed by intention does not provide any skills related to Sustainability. As a result, all scores and Index of C_i for each category are represented by value 0.

Table 7.4 Index value for each category (PD from course A)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Score	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MSi(PD)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Index of C_i $_{(i=1-15)}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Teacher´s feedback on the questionnaire

Table 7.5 depicts the outcomes from the analysis in terms of responses, average score (MSi(Att)) and Index of C_i. In general, the teacher was expected that at the end of the course, the students will have positive responses on all the items or in other words students will either agree or strongly agree on all the statements. By exceptions there were neutral stands on the statements in green /eco technology category (C_4), equity category (C_8), culture category (C_{10}), global issues category (C_{14}) and local issues category (C_{15}).

The following are some of the responses of the teacher that were in disagreement and neutral stand points on the items. The teacher disagreed with a statement that global security is a part of the future engineers' responsibilities. Whereby, the teacher has a neutral stand on the role of future engineer to solve poverty, the impacts of engineering to the local and the importance of local aspirations in engineering solutions.

Global security is a part of their responsibility (Disagreement stand)
They will take part in solving poverty (Neutral stand)
They will identify potential impacts of engineering to the local (Neutral stand)
Local aspirations are important for them in engineering solutions (Neutral stand)

Table 7.5 Index value for each category (Attitude survey from course A)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Score	7	7	4	3	9	4	7	3	8	3	4	7	8	5	6
MSi(Att)	3,5	3,5	4	3	4,5	4	3,5	3	4	3	4	3,5	4	2,5	3
Index of $C_{i\ (i=1\text{-}15)}$	0,7	0,7	0,8	0,6	0,9	0,8	0,7	0,6	0,8	0,6	0,8	0,7	0,8	0,5	0,6

Graphically the indicator in Figure 7.6 illustrates that the teacher´s responses on attitude towards sustainability fluctuate according to categories. There are positive attitudes in all categories (categories that are indicated outside the consenting threshold) except for category C4, C8, C10, C14 and C15.

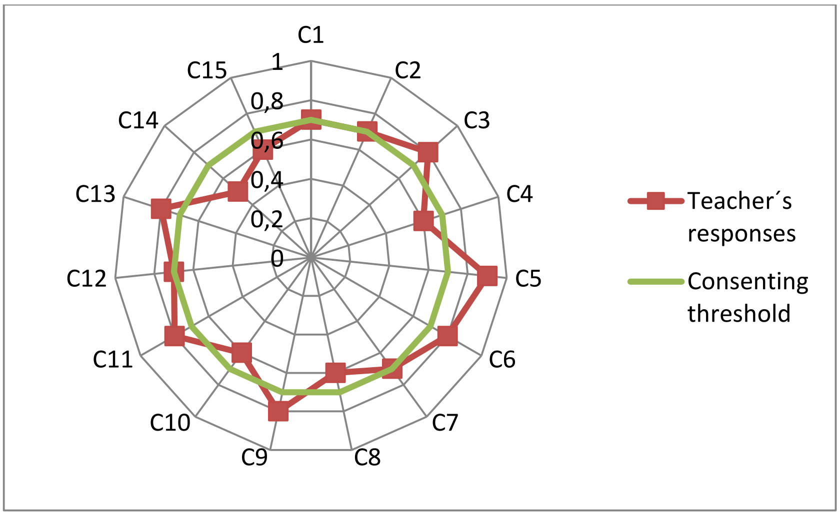


Figure 7.6 Sustainability attitude provided in Case A

Students´ concept maps

Figure 7.7, 7.8 and 7.9 show captions of C-Maps drawn by three students for Case A. Both Figure 7.7 and 7.8 are similar in terms of how the concepts and sub-concepts are linked to the main concept of sustainable technology. The concepts are connected without linking words e.g. "consist of" and "provided by". Both students relate sustainable technology with global issues, local issues and quality in engineering. They also perceived that global issues are connected to environmental issues and local issues are connected to social issues such as issues related to social rights/values and equity between generations. They perceived that quality in engineering is connected to the empowerment of engineer.

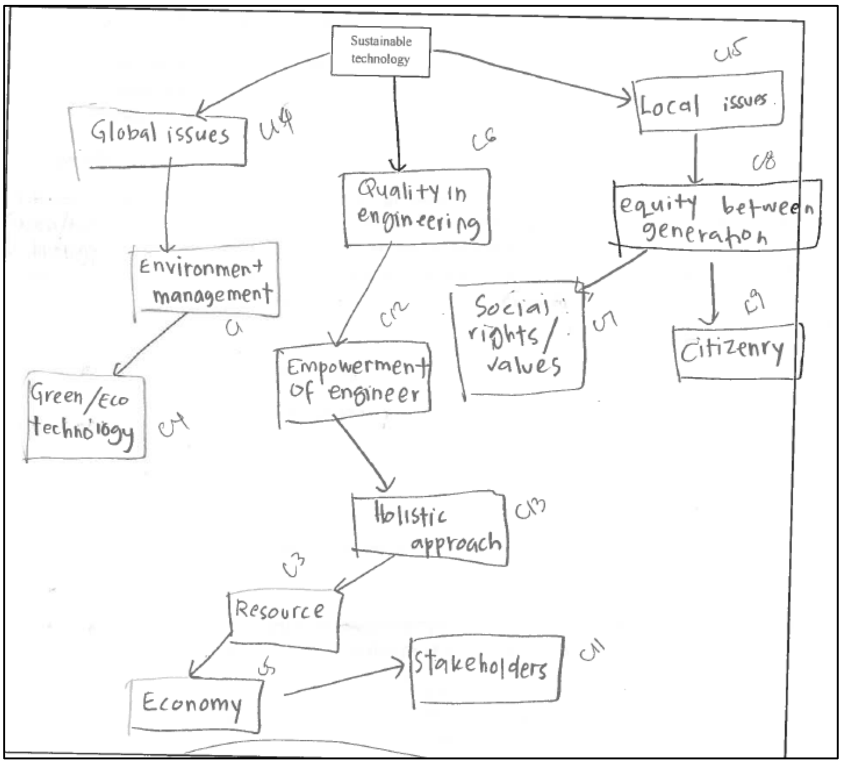


Figure 7.7 Conceptual maps drawn by student I2C1R2

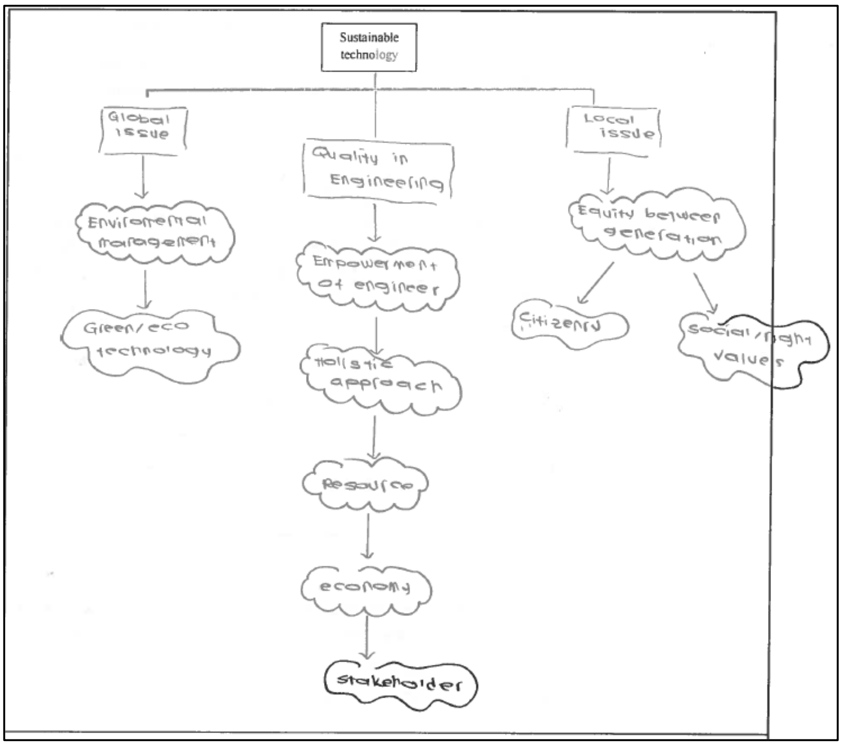


Figure 7.8 Conceptual maps drawn by student I2C1R3

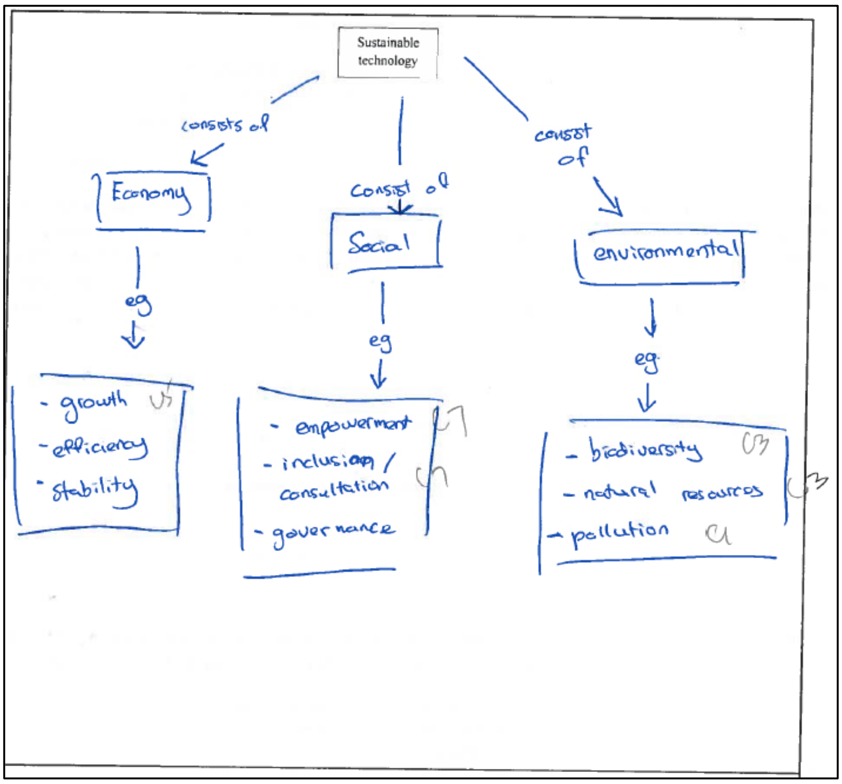


Figure 7.9 Conceptual maps drawn by student I2C1R14

In developing conceptual maps for Sustainable technology, student I2C1R14 linked the main concept with three keys of sustainability, economy, social and environmental. The conceptual maps were further expanded by providing some examples related to the sub-concepts. The student pointed out that growth, efficiency and stability are related to economy; empowerment, consultation and governance are related to social; biodiversity, natural resources and pollution are related to environmental.

The following table depicts the summary of the responses of all sixteen students. Most of the students were able to develop conceptual maps of sustainable technology based on their own understanding. Except the three students who were absent, all students connected the concept of sustainable technology with environmental management and most of them linked the concepts with resources, green technology, economic, global and local issues. However fewer students have linked the main concept with culture. The furthest left column of the table shows that the percentages of categories were linked to the main concept for each of the students. Four out of thirteen students were unable to link the main concepts with almost 75% of the categories and the remaining students linked the main concepts with over 80% of the categories.

Table 7.6 Index value for each category (Students´ C-Maps from Case A)

Respondent	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	% C_i
$I_2C_1R_1$	1			1												13
$I_2C_1R_2$	1	1	1	1	1	1		1	1		1	1		1	1	80
$I_2C_1R_3$	1	1	1	1	1	1	1	1	1		1	1	1	1	1	93
$I_2C_1R_4$																0
$I_2C_1R_5$																0
$I_2C_1R_6$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_1R_7$	1	1	1		1	1	1	1	1	1	1	1	1	1	1	93
$I_2C_1R_8$	1	1	1	1	1	1		1	1	1	1	1	1	1	1	93
$I_2C_1R_9$	1	1	1	1	1	1	1	1	1	1		1	1	1	1	93
$I_2C_1R_{10}$	1		1	1										1		27
$I_2C_1R_{11}$																0
$I_2C_1R_{12}$	1				1		1								1	27
$I_2C_1R_{13}$	1		1		1		1									27
$I_2C_1R_{14}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_1R_{15}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_1R_{16}$	1	1	1	1	1	1	1	1	1		1	1	1	1	1	93
Total score of $C_{i\ (i=1\text{-}15)}$	13	9	11	10	11	9	9	9	9	6	8	9	8	10	10	
Samples N	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	
Index of C_i (i=1-15)	1,0	0,7	0,8	0,8	0,8	0,7	0,7	0,7	0,7	0,5	0,6	0,7	0,6	0,8	0,8	

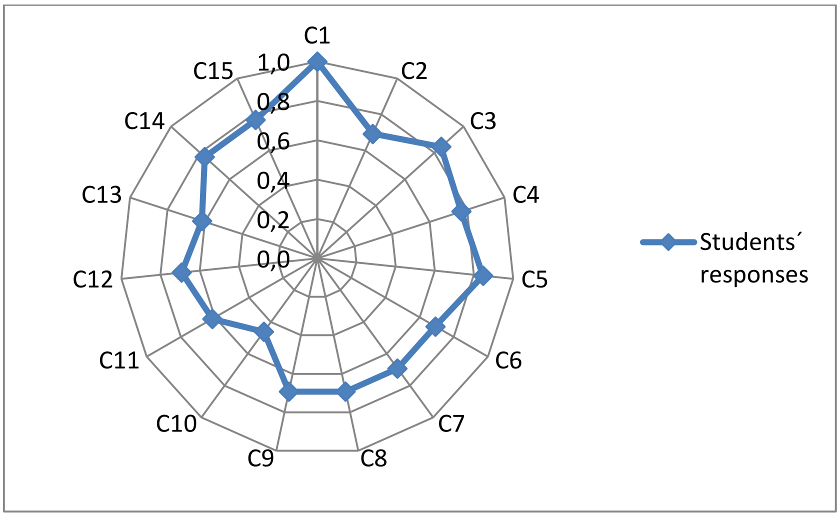


Figure 7.10 Sustainability knowledge obtained from Case A

The indicator of sustainability knowledge depicted in Figure 7.10 demonstrates that all students are able to connect the concept of sustainability in engineering with the knowledge related to environmental management. It also demonstrates that majority of the students were able to connect all sustainability components such as green technology, quality in engineering, social rights or social values, and equity amongst generations except half of the students who were unable to connect culture to the concepts of sustainability in engineering.

Students´ procedural diagram

The following Figure 7.11, 7.12 and 7.13 are evidences of the use of procedural diagrams and self-rate procedures as evaluation tool to measure the obtained sustainability skills. Student I2C1R8 provided a procedure on how in his/her perspectives the skills are needed to produce a sustainable technology. The respondent highlights that in the analysis process, it is needed to identify problem and do pros and contras analysis. And both skills were scored as “2” which described that the respondent is experienced in applying those skills on difficult task. From the diagram, the researcher has coded the skills into category C2, C4 and C12 and averaged the scores according to the categories.

Different with student I2C1R8, student I2C1R13 highlighted that it is needed to identify the problem background, find previous researches on sustainable technology and administer a set of questionnaire about the current sustainable technology in the cycle of analysis. The respondent rated his/her self on two of the skills as master level and one of the skills as expert level. However, from the analysis the data show that the respondent only highlighted two components of sustainability in engineering which are categorized under empowerment of engineer and holistic/systemic approach.

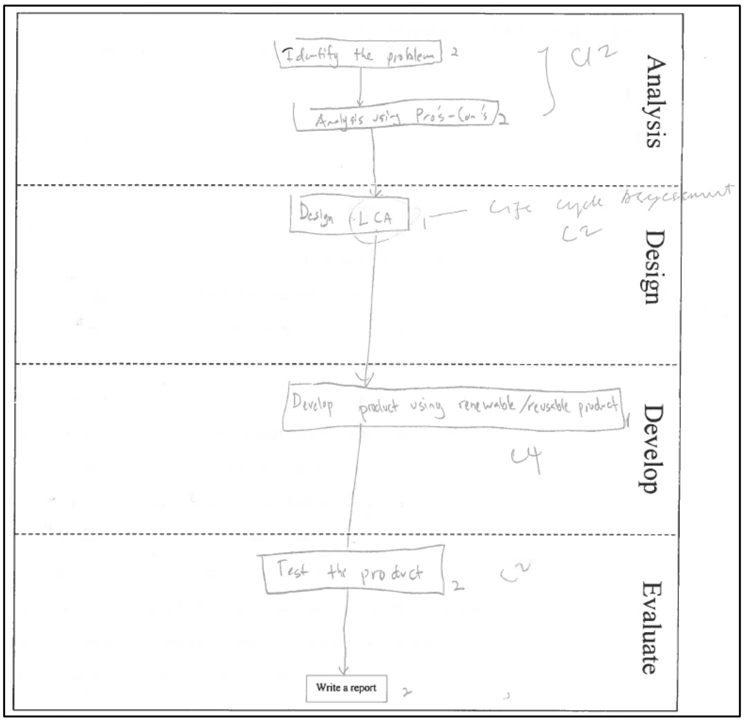


Figure 7.11 Procedural diagrams drawn by student I2C1R8

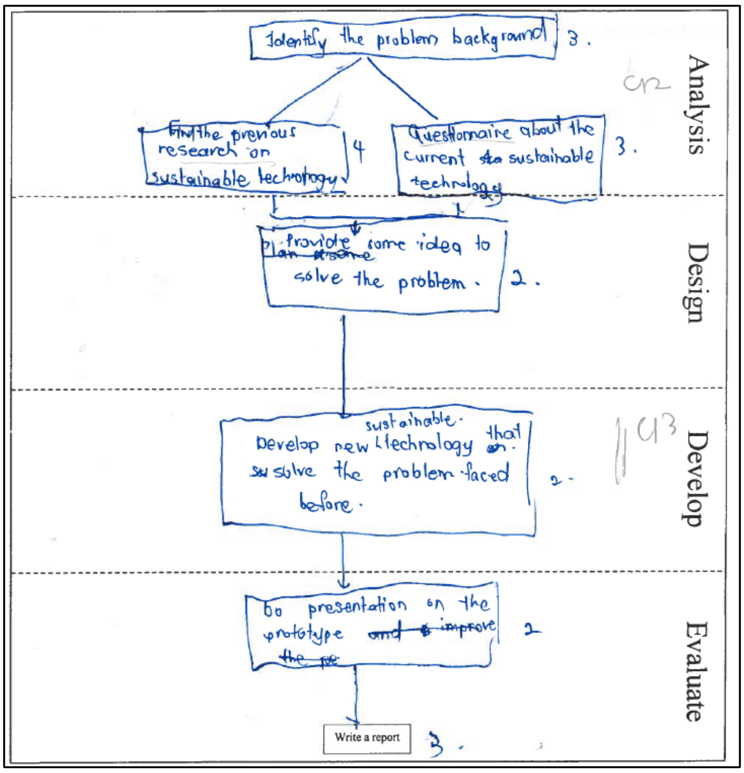


Figure 7.12 Procedural diagrams drawn by student I2C1R13

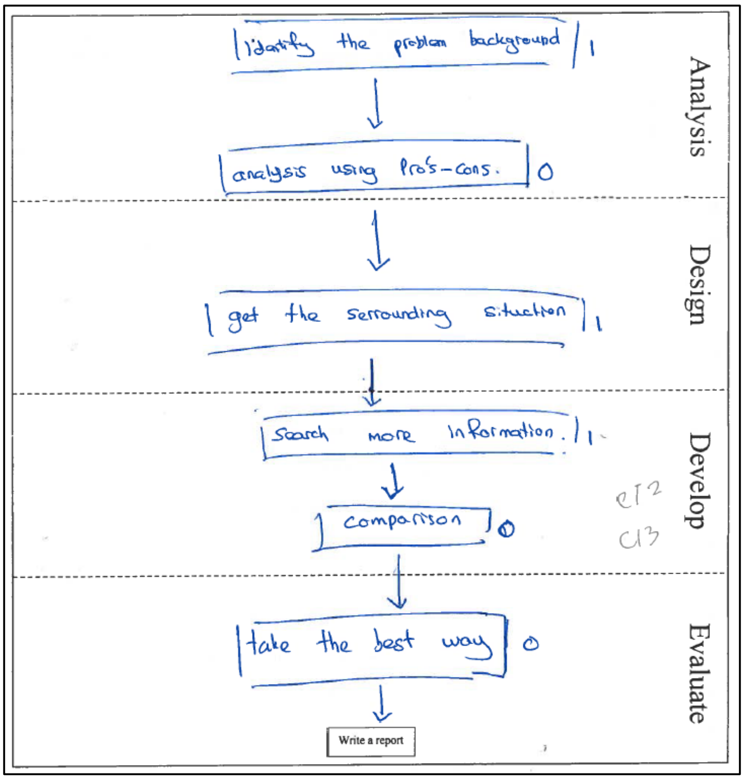


Figure 7.13 Procedural diagrams drawn by student I2C1R14

Figure 7.13 depicts another example of the respondent's feedback on the procedural diagram. The respondent showed some effort to provide a complete procedure to produce a sustainable technology. The respondent rated himself as basic level, who is only experienced in applying the skill of identifying problem background on simple task and somewhat showed his/her ability to apply systemic approach (from the diagram) on simple task. Therefore, the respondent earned a score of 1 under the category of empowerment of engineer and holistic/systemic approach.

Besides of the ability of these respondents in structuring procedural diagrams, the study has shown that majority of the respondents have left the research instrument unanswered (boxes shaded in grey). This is either because the respondents believe Case A is unable to prepare them to answer the question or the respondents do not understand the question.

Table 7.7 Index value for each category (Students´ PD from Case A)

Respondent	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
$I_2C_1R_1$															
$I_2C_1R_2$															
$I_2C_1R_3$															
$I_2C_1R_4$															
$I_2C_1R_5$															
$I_2C_1R_6$															
$I_2C_1R_7$															
$I_2C_1R_8$		1,5		1								2			
$I_2C_1R_9$															
$I_2C_1R_{10}$															
$I_2C_1R_{11}$															
$I_2C_1R_{12}$							1,5								
$I_2C_1R_{13}$												1	1		
$I_2C_1R_{14}$												2	3		
$I_2C_1R_{15}$															
$I_2C_1R_{16}$															
Total score of $C_{i\ (i=1\text{-}15)}$	0	1,5	0	1	0	0	1,5	0	0	0	0	5	4	0	0
Samples N	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Index of C_i $_{(i=1\text{-}15)}$	0	0,1	0	0,1	0	0	0,1	0	0	0	0	0,3	0,3	0	0

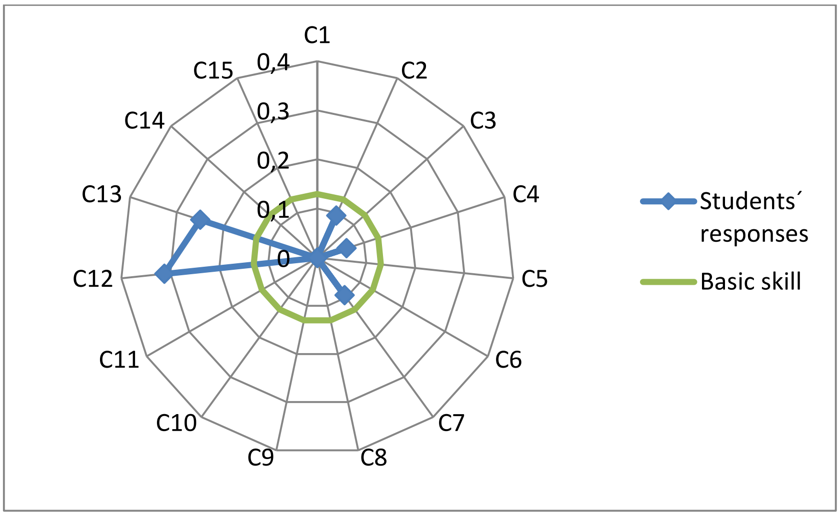


Figure 7.14 Sustainability skills obtained from Case A

The indicator shows that the respondents obtained the skills of or related to environmental assessments, green/eco technology, social rights/values, empowerment of engineer and holistic/systemic approach. However, according to Figure 7.14, only two sustainability components pass the basic skill level (the scores are plotted outside the green circle) and the other three components are below the basic skill level.

Students´ responses on the questionnaire

The students´ responses on 32 items have been analysed with statistical approach presented in Chapter 4. The outcomes from the analysis are then organized into the following Table 7.8. It shows that all respondents responded on the questionnaires. With a response rate of 100%, the analysis on the responses can provide an understanding on the students´ attitudes towards sustainability obtained from Case A.

Table 7.8 Index value for each category (Students´ feedbacks from Case A)

Respondent	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
$I_2C_1R_1$	3	4	4	4	4	5	4	3,3	4	4	3	3,5	3	4	3
$I_2C_1R_2$	3,5	3,5	4	4	3	4	4	3,7	4	4	4	4	3,5	3,5	3,5
$I_2C_1R_3$	5	4	5	5	4	5	4,5	3,7	5	5	4	5	5	4,5	5
$I_2C_1R_4$	3,5	4,5	4	5	3,5	5	4	3,7	4	4	3	4,5	4	4	4
$I_2C_1R_5$	4	4,5	4	4	4	5	4,5	3,7	4,5	4	3	4	4	4	4
$I_2C_1R_6$	4	4	5	5	4	5	3	4,0	4,5	4	3	4	3,5	3,5	3
$I_2C_1R_7$	3,5	3	5	5	4	5	4,5	5,0	4,5	4	4	4	4	3,5	4
$I_2C_1R_8$	3	3	5	4	4	4	4	3,0	3,5	4	3	4	5	3,5	4
$I_2C_1R_9$	4	2,5	5	5	4,5	5	4,5	4,3	5	5	3	5	5	3,5	4,5
$I_2C_1R_{10}$	4	3,5	4	5	3,5	4	5	4,0	4	4	4	4,5	3	4,5	4,5
$I_2C_1R_{11}$	3	4,5	5	5	4	5	4,5	3,7	5	5	5	3,5	3	3	3
$I_2C_1R_{12}$	4,5	3,5	3	4	3,5	4	3,5	3,0	4	4	4	4,5	4	5	3,5
$I_2C_1R_{13}$	5	5	5	5	5	5	5	4,3	5	5	4	4	5	5	5
$I_2C_1R_{14}$	4	4	4	4	4,5	5	4	3,3	4,5	4	3	4	4	3,5	3,5

$I_2C_1R_{15}$	3,5	4	3	4	4,5	5	5	4,0	5	4	5	4,5	4	4,5	3,5
$I_2C_1R_{16}$	3	4	5	5	3	5	4	4,3	4,5	4	3	3	4	3	3
Average of $C_{i\ (i=1\text{-}15)}$	3,8	3,8	3,9	4,0	3,9	3,8	4,3	3,8	4,4	3,9	4,1	4,1	4	3,9	3,8
Samples N	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Index of C_i $(i=1\text{-}15)$	0,8	0,8	0,8	0,8	0,8	0,8	0,9	0,8	0,9	0,8	0,8	0,8	0,8	0,8	0,8

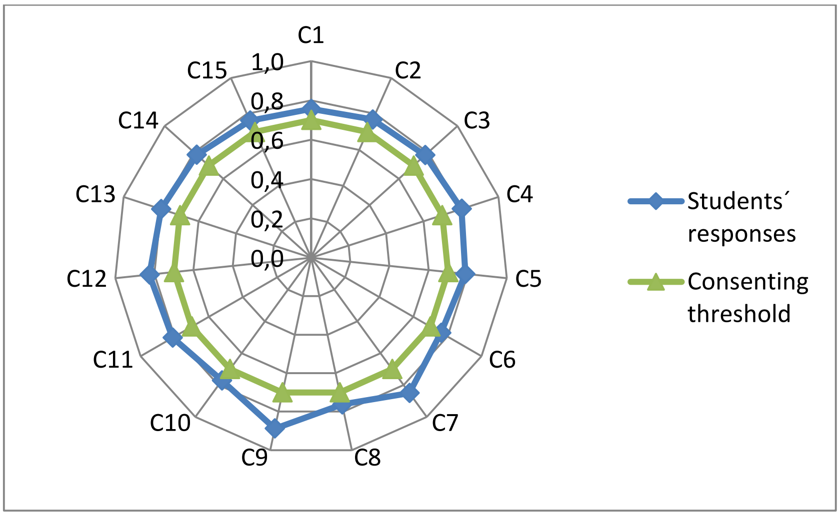


Figure 7.15 Sustainability attitudes obtained from Case A

The indicator in Figure 7.15 indicates that all students have a positive attitude on every sustainability components. The indicator also highlights that in average all students have a strong agreement towards components in category C7 and category C9. From both categories, there is evidence of strong agreement amongst the respondents on the importance for them to protect social rights and to contribute to human health. There are also evidences of strong agreements on the role of future engineers to take into consideration the needs of society/community and responsibility not only in the company but also outside the company.

7.3.2. Case B

Analysis on the documented learning objectives

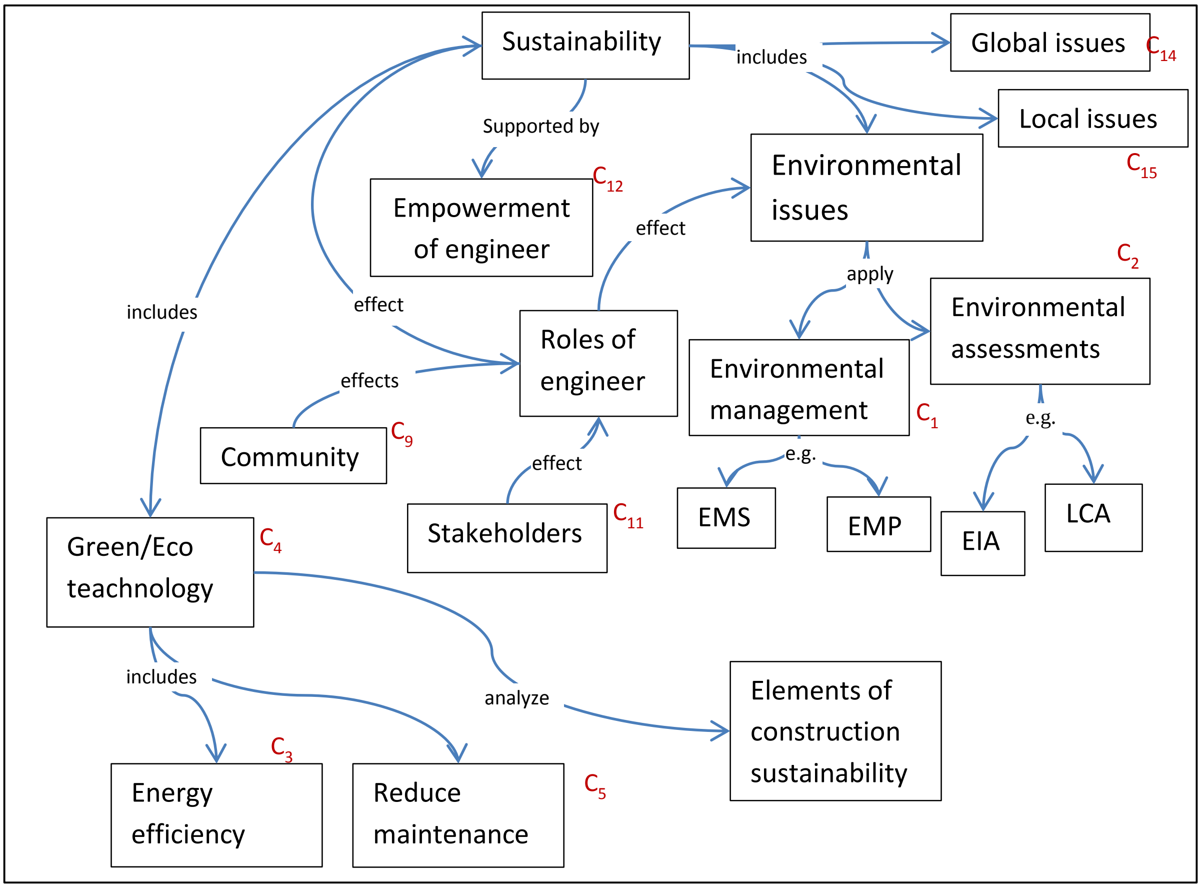


Figure 7.16 Concept map for C2

The above figure illustrates the conceptual map for Case B. The map is constructed by the researcher by converting the documented learning objectives into several key concepts (sustainability components) related to the concepts of sustainability. The map also demonstrates the complexity of the connection between the key concepts. In this case, several sustainability components have been incorporated in the engineering course which comprise issues related to environmental management, environmental assessments, resources, green/eco technology, economic, citizenry, stakeholders, holistic/systemic approach, global issues and local issues.

Table 7.9 Index values for Case B

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Response	1	1	1	1	1	0	0	0	1	0	1	1	0	1	1
Index of C_i $(i=1\text{-}15)$	1	1	1	1	1	0	0	0	1	0	1	1	0	1	1

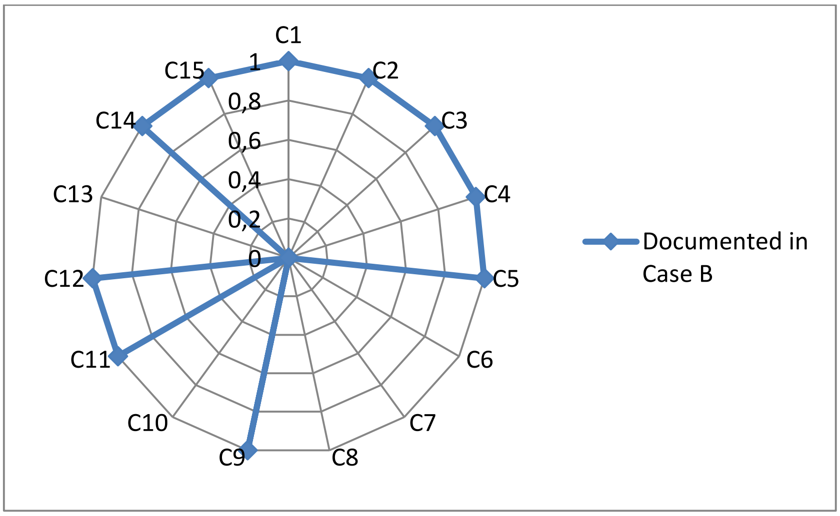


Figure 7.17 Sustainability knowledge documented in Case B

Teacher´s concept maps

According to Figure 7.18, C-Map from Case B shows different expectations from the students compared to expectations from students in Case A. The teacher believes (highlighted) that at the end of the course, students are able to learn five components of sustainability. The components are local issues (C_{15}), global issues (C_{14}), environmental management (C_1), green technology (C_4), and resources (C_3).

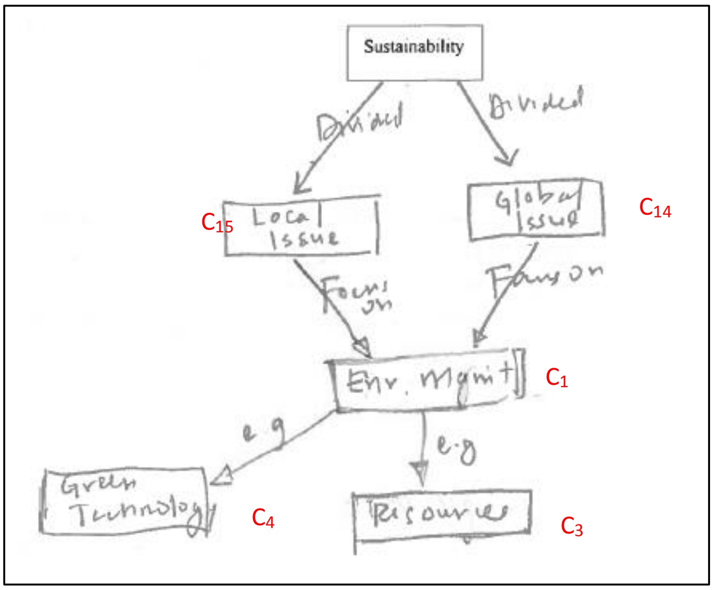


Figure 7.18 Conceptual maps drawn by teacher I3C2

Table 7.10 depicts that all five categories are weighted with score 1 in the Response column and valued with 1 in Index of C_i column.

Table 7.10 Index value for each category (C-Maps from course B)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Response	1	0	1	1	0	0	0	0	0	0	0	0	0	1	1
Index of C_i $_{(i=1\text{-}15)}$	1	0	1	1	0	0	0	0	0	0	0	0	0	1	1

Figure 7.19 illustrates that Case B provided sustainability knowledge by focusing on five categories of sustainability. The teacher expected that at the end of the course the students are able to obtain knowledge in the area of environmental management, resources, green or eco technology, global and local issues. The indicator also explains that the indication is partly aligned with the documented sustainability knowledge in Case B. The case is aimed to introduce the concepts of sustainability by bringing global and local issues, environmental management and issues related to resources and green or eco technology. However, based on the researcher's conceptual map for Case B (see Figure 7.17), the case also provides knowledge on environmental assessments, issues on community, stakeholders and the empowerment of engineer.

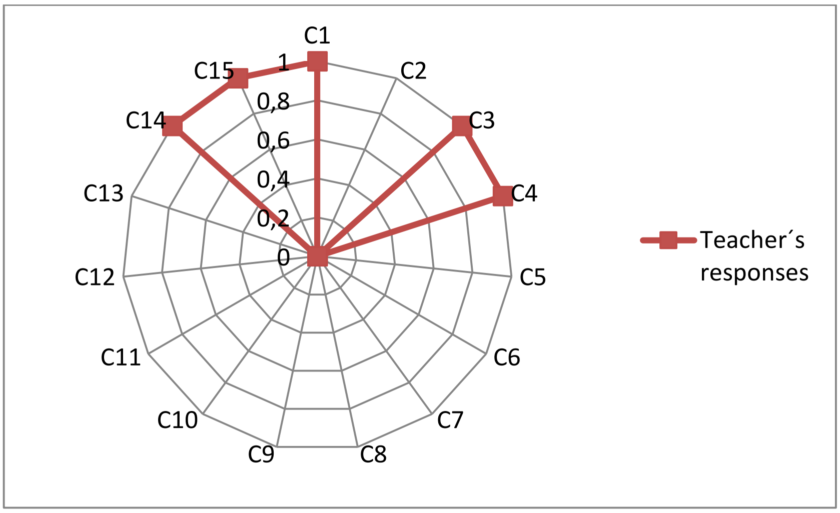


Figure 7.19 Sustainability knowledge provided by Case B

Teacher´s procedural diagram

Figure 7.20 illustrates the procedural diagrams drawn by the teacher to interpret the expected learning outcomes in terms of skills. The teacher interpreted that the course provides skills only at analysis and evaluate stages. The skills provided are also focused on Empowerment of Engineer, C_{12}.

After the stated skills were coded, the total score of each of the category was calculated.

$$\text{Total scores for } C_{12} = 1 + 1 + 1 + 1$$
$$= 4$$

The total score for C12 is administered in Table 7.11. Note that the total scores for other categories are valued with 0. By carrying the total score for C_{12} = 4, the *MSi(PD)* was calculated as 1 and the Index of C_{12} was 0.3.

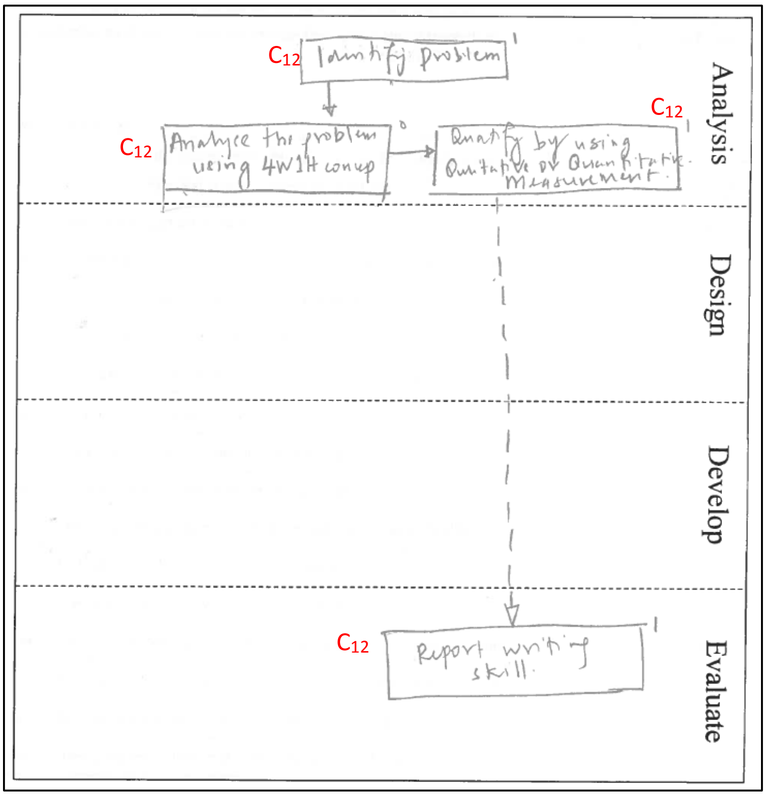


Figure 7.20 Procedural diagrams drawn by teacher I3C2

Table 7.11 Index value for each category (PD from course B)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Total score	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
MSi(PD)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Index of C_i $_{(i=1\text{-}15)}$	0	0	0	0	0	0	0	0	0	0	0	0,3	0	0	0

The indicator for sustainability skills illustrates that the only sustainability skill provided in Case B is the skill to empower engineer e.g. communication skills. The students are expected to be able to apply the skill for simple tasks and not for complex tasks. By comparing the results from the indicator and the documented learning objectives in Case B, the course actually provided skills in other categories such as stakeholders category (C11) and local issues category (C15).

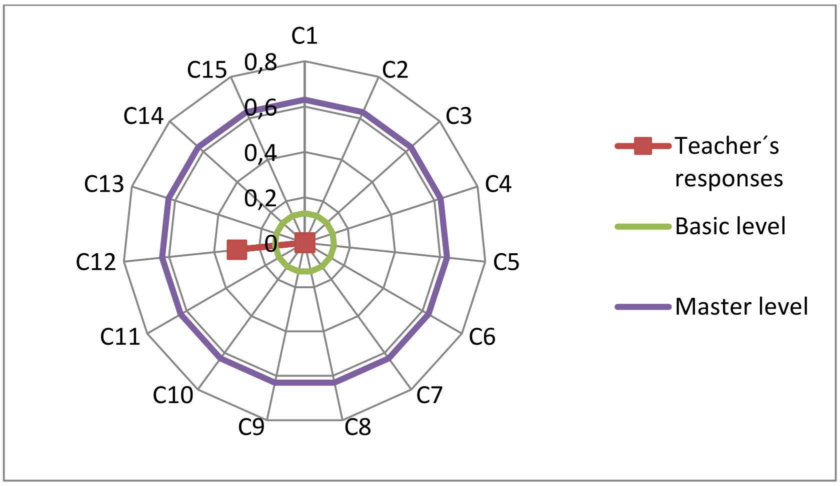


Figure 7.21 Sustainability skills provided for course B

Teacher´s feedbacks on the questionnaire

Based on the analysis of teacher´s expectations on students´ attitude toward sustainability, it was found that all the items have positive responses. In addition, only one out of fifteen categories has “agree” response, the remaining categories have “strongly agree” responses. The category that has an index value within the range of 0.70 to 0.89 is in “stakeholders” category (C11).

Table 7.12 Index value for each category (Attitude survey from Case B)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Score	10	10	5	5	9	5	9	14	9	5	4	9	10	9	10
MSi(Att)	5	5	5	5	4,5	5	4,5	4,7	4,5	5	4	4,5	5	4,5	5
Index of C_i (i=1-15)	1	1	1	1	0,9	1,0	0,9	0,9	0,9	1	0,8	0,9	1	0,9	1

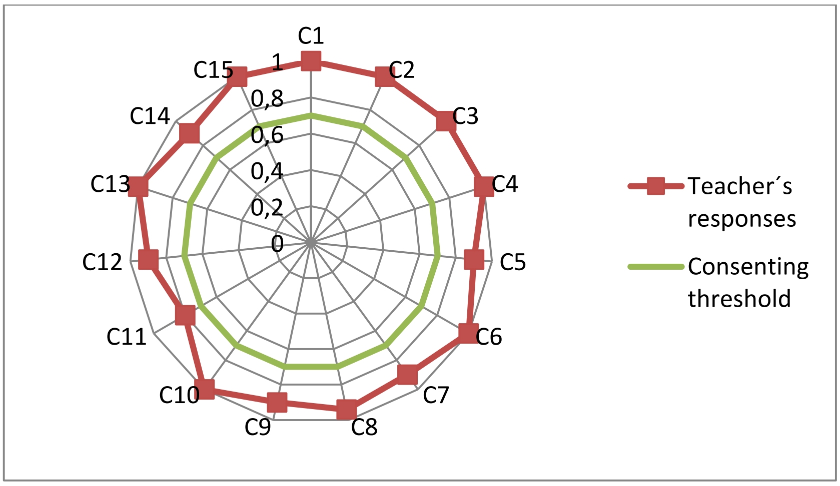


Figure 7.22 Sustainability attitude provided for course B

Students´ concept maps

The following figures illustrate the conceptual maps drawn by three of the students from Case B. Each of them is unique. For student I2C2R2, sustainable technology can be directly linked with environmental management and green/eco technology categories. Both categories are also linked economy category. The conceptual maps drawn by the student have slightly complex connections, the key categories are cross connected and some sub-concepts are interconnected. Referring to Figure 7.24, student I2C2R5 has identified several key categories linked to the main concept. The concept has been divided into economy, culture, citizenry and local issues. The student has also conceptualized sustainable technology into environmental management, stakeholders, green/eco technology and global issues.

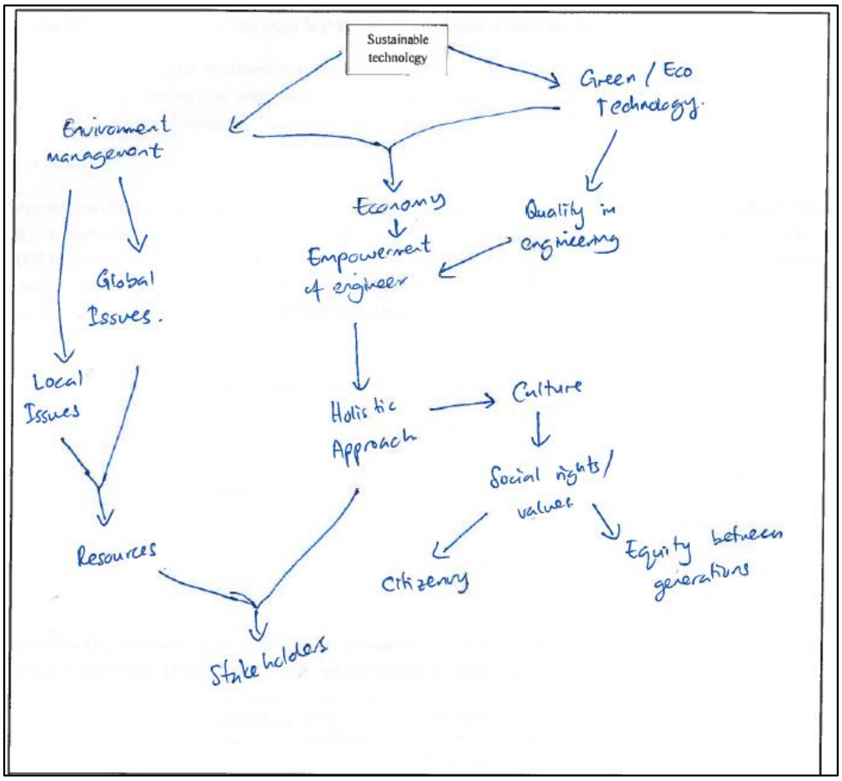


Figure 7.23 Conceptual maps drawn by student I2C2R2

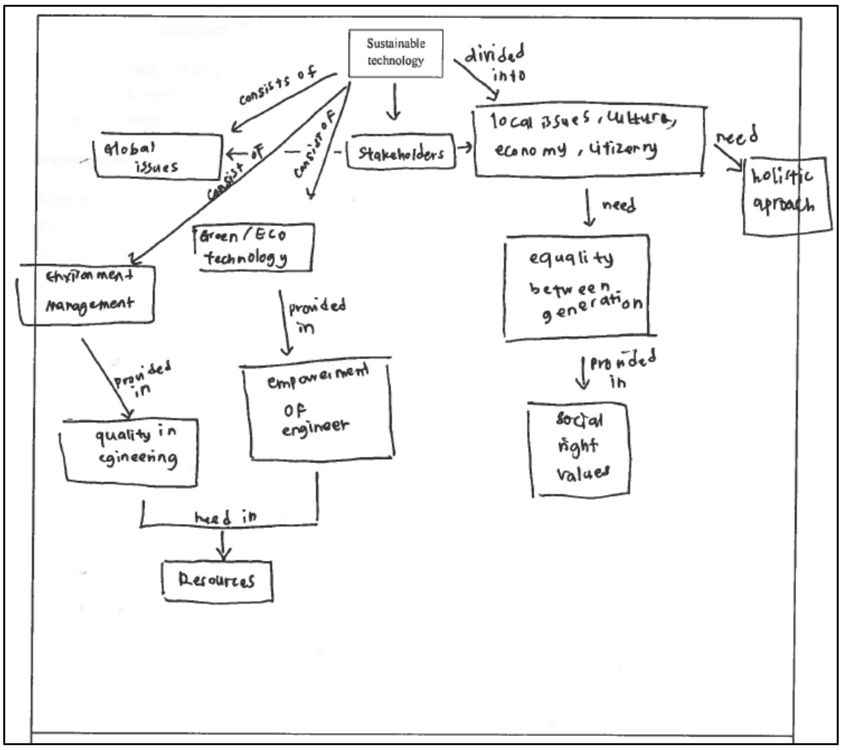


Figure 7.24 Conceptual maps drawn by student I2C2R5

For student I2C2R7, sustainable technology consists of environmental management, green/eco technology and empowerment of engineering. However, these key categories are further extended to the sub-concepts with unclear linking words. Some of the categories are merely connected regardless of its significance. For instance, the relation between environmental management and social rights/value are linked as an example.

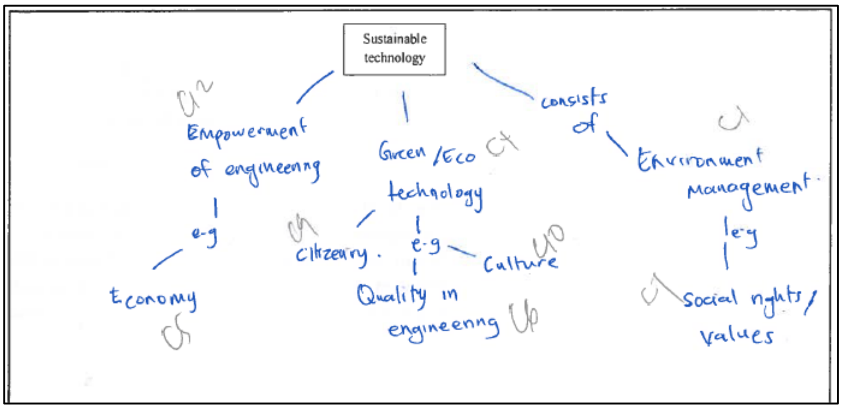


Figure 7.25 Conceptual maps drawn by student I2C2R7

Table 7.13 Index value for each category (Students´ C-Maps from course B)

Respondent	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	% C_i
$I_2C_2R_1$	1	1	1	1		1	1			1		1		1	1	67
$I_2C_2R_2$	1	1	1		1				1	1				1		47
$I_2C_2R_3$	1	1				1	1					1	1			40
$I_2C_2R_4$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_2R_5$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_2R_6$	1	1		1	1	1	1		1	1		1				60
$I_2C_2R_7$	1	1	1	1	1	1	1	1	1	1	1		1	1	1	93
$I_2C_2R_8$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_2R_9$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_2R_{10}$	1	1	1	1	1		1	1				1	1	1	1	73
$I_2C_2R_{11}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_2R_{12}$	1	1		1	1	1	1	1	1	1	1	1		1	1	87
$I_2C_2R_{13}$	1	1	1	1	1						1			1		47
$I_2C_2R_{14}$	1	1	1	1	1	1	1		1	1	1	1		1		80
$I_2C_2R_{15}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_2R_{16}$	1	1	1	1		1	1			1		1		1	1	67
Total score of $C_{i\ (i=1\text{-}15)}$	15	15	12	13	13	12	13	9	11	12	10	12	9	13	10	
Samples N	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	
Index of $C_{i\ (i=1\text{-}15)}$	1,0	1,0	0,8	0,9	0,9	0,8	0,9	0,6	0,7	0,8	0,7	0,8	0,6	0,9	0,7	

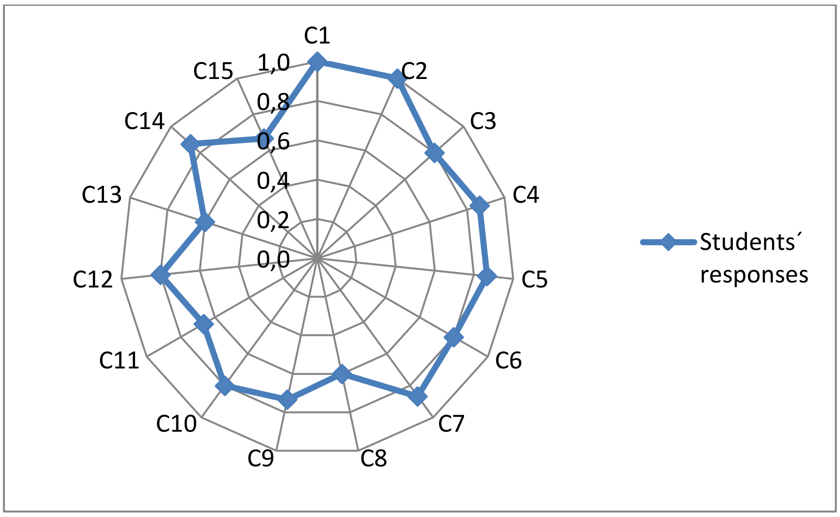


Figure 7.26 Sustainability knowledge obtained in Case B

The above table shows the analysis of sixteen students´ conceptual maps in terms of its average score, index values and percentage of component (see column % C_i in Table 7.13). From the analysis, thirteen of the students are able to connect more than 50% of the sustainability components to the concept of sustainable technology and six of them are able to connect all components. Figure 7.26 on the other hand, depicts the index values (represent the percentage of students) of each of the categories that are connected to the concepts of sustainability. The results show that all students have mutually connected the concepts of sustainability with issues related to environmental management and environmental assessments. Meanwhile, the least values are in the categories of equity of generations and holistic/systemic approach.

Students´ procedural diagrams

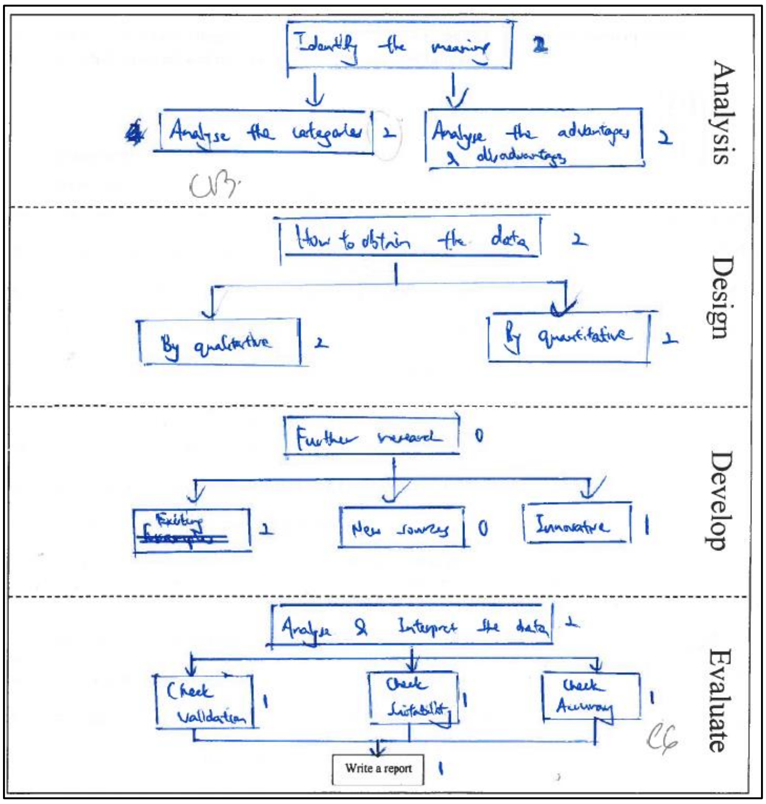


Figure 7.27 Procedural diagrams drawn by student I2C2R8

Similarly, in this section the researcher presents the three examples of the students´ feedbacks on the procedural diagrams and self-rated procedures. Student I2C2R8 completed his/her diagram without connecting the skills between design cycles. However, the student highlights issues related to holistic/systemic approach and somewhat related to quality in engineering.

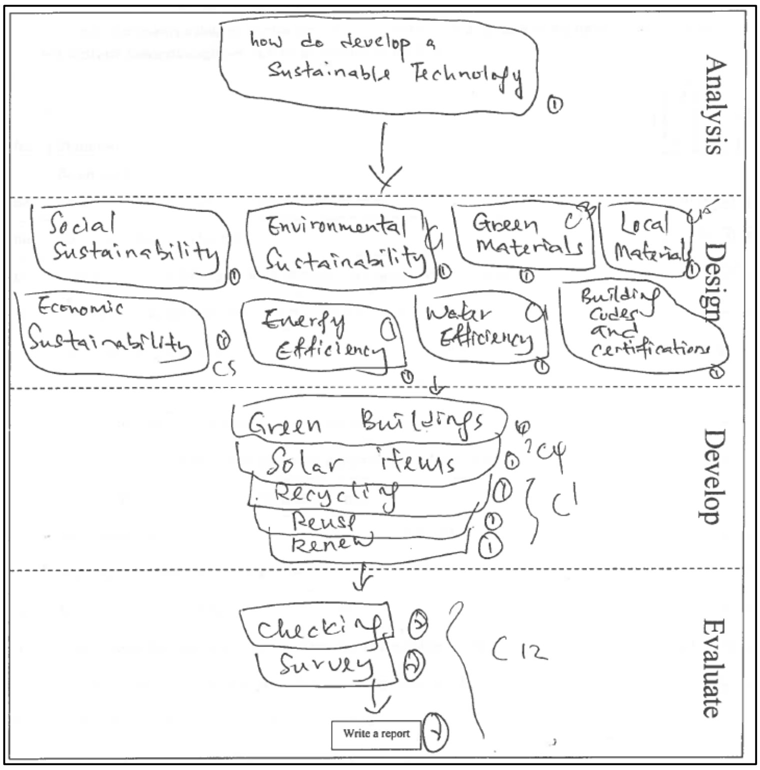


Figure 7.28 Procedural diagrams drawn by student I2C2R9

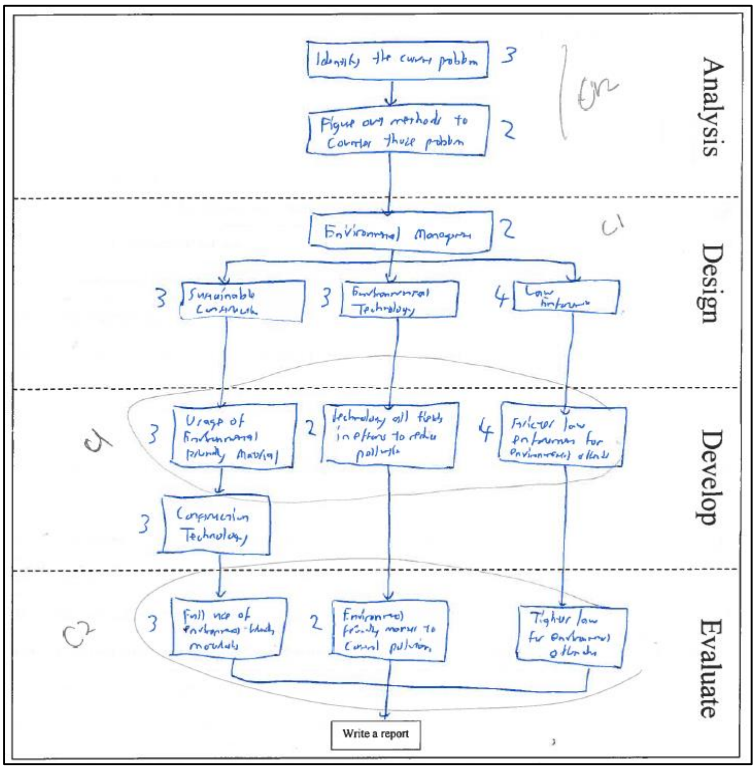


Figure 7.29 Procedural diagrams drawn by student I2C2R10

In Figure 7.28, the student provides several issues on sustainability. Even though the procedural diagram has to be constructed in the form of skills, the student provided the issues in the form of concepts that are related to sustainability. In order to analyse the data, the researcher has to relate the provided concepts with the cycle of design (referring to which part the concepts are provided). It is found that, the student highlights the skills that are related to the issues of environmental management, resources, green/eco technology, quality in engineering, economic and empowerment of engineer. The provided diagram in Figure 7.29 is well structured, and has been built on several sustainability skills. The student has connected the process of developing sustainable technology with skills related to environmental management, environmental assessment and empowerment of engineer.

Table 7.14 Index value for each category (Students´ PD from Case B)

Respondent	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
$I_2C_2R_1$															
$I_2C_2R_2$												1			
$I_2C_2R_3$															
$I_2C_2R_4$															
$I_2C_2R_5$															
$I_2C_2R_6$															
$I_2C_2R_7$															
$I_2C_2R_8$						1						1	1		
$I_2C_2R_9$						1						2	2		
$I_2C_2R_{10}$	1	1		1	1							2	1		1
$I_2C_2R_{11}$	3	2,5										2,5	3		
$I_2C_2R_{12}$						1	1					1			
$I_2C_2R_{13}$															
$I_2C_2R_{14}$												4			
$I_2C_2R_{15}$												4			
$I_2C_2R_{16}$												1,5			
Total score of $C_{i\ (i=1\text{-}15)}$	4	3,5	0	1	1	3	1	0	0	0	0	19	7	0	1
Samples N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Index of $C_{i\ (i=1\text{-}15)}$	0,1	0,1	0	0,0	0	0,1	0	0	0	0	0	0,5	0,2	0	0

The response rate for this instrument is 56 % where 44 % of the instruments are returned non-responded. Table 7.14 shows the analysis of the data into mean and index values, and the data are converted in the following figure. From the figure, it is demonstrated that there are only two sustainability components obtained by the students above the basic skill level (outside the green circle). Both sustainability skills are related to area in empowerment of engineer and holistic approach, whereby the other three sustainability skills (environmental management, environmental assessments and quality in engineering) are below the basic skill level.

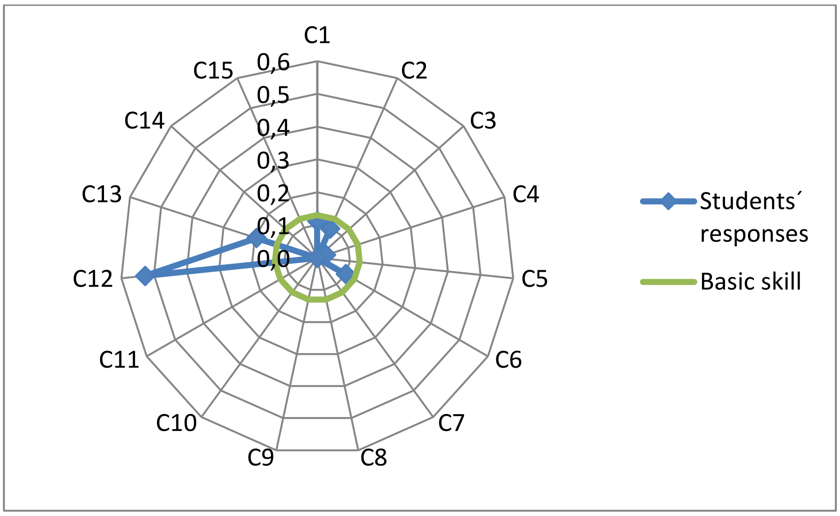


Figure 7.30 Sustainability skills obtained from Case B

Students´ responses on the questionnaire

Table 7.15 Index value for each category (Students´ feedbacks from Case B)

Respondent	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
$I_2C_2R_1$	3,5	4,5	4	4	5	5	4,5	4,7	4	4	4	3,5	4	4	5
$I_2C_2R_2$	3	4	5	4	3,5	3	3,5	3,7	4	4	4	4	3,5	2	2,5
$I_2C_2R_3$	2,5	3	3	3	3	4	3,5	3,7	3	3	3	2,5	3	3	3,5
$I_2C_2R_4$	4	4	5	5	4	5	4	3,3	4	4	4	4,5	5	5	4,5
$I_2C_2R_5$	4	4,5	5	5	3	5	5	4,3	4,5	4	5	4	5	5	5
$I_2C_2R_6$	3	3,5	4	5	4,5	4	5	4,3	4	4	3	4	3,5	4	5
$I_2C_2R_7$	4	4,5	5	5	3,5	5	4,5	3,0	5	4	3	4,5	4	4,5	4
$I_2C_2R_8$	4,5	4	4	5	4	5	4	3,0	5	4	4	4	4,5	4	4
$I_2C_2R_9$	3	3,5	3	3	5	5	3,5	3,3	4,5	4	4	4,5	4	3	4
$I_2C_2R_{10}$	4	4,5	5	5	4,5	4	5	4,3	4,5	4	4	4,5	4	4	4
$I_2C_2R_{11}$	4	4	4	4	4	4	4	4,0	4	4	4	4	4	4	4
$I_2C_2R_{12}$	4	5	5	4	4	4	4	4,7	4	4	4	4,5	4	4	4
$I_2C_2R_{13}$	4,5	4,5	3	3	3	3	3,5	4,0	3,5	3	4	3,5	3,5	3	3,5
$I_2C_2R_{14}$	3,5	3,5	3	5	3,5	3	3,5	3,0	3,5	3	4	3,5	3,5	4,5	3,5
$I_2C_2R_{15}$	3	3	3	4	4,5	3	2,5	3,0	4	3	3	4	3,5	3,5	2,5
$I_2C_2R_{16}$	3	3,5	3	4	4	4	4,5	3,3	4	3	4	4,5	3,5	4	4
Average of $C_{i\ (i=1\text{-}15)}$	3,6	4,0	3,8	3,9	3,9	3,8	4,0	3,7	4,1	3,9	4,1	4,0	3,9	3,8	3,9
Samples N	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Index of C_i $_{(i=1\text{-}15)}$	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,8

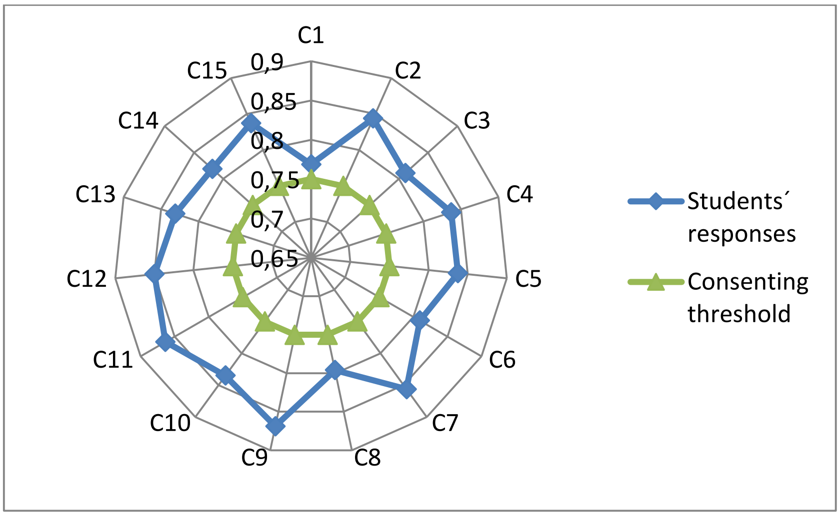


Figure 7.31 Sustainability attitudes obtained from Case B

From the analysis, it is found that all students´ tend to agree with all items in the research instrument. The figure shows that the students strongly leaned to agree on the items in citizenry category where as future engineers, they will take into consideration the needs of society/community and they are responsible not only in the company but also outside of the company. Meanwhile, the students slightly leaned to agree that as the future engineer they will manage the foreseen pollutions and their aim is to eliminate all waste products.

7.3.3. Case C

Analysis on the documented learning objectives

As result from converting the documented learning objectives into conceptual maps, the researcher has found that there are four components of sustainability that have been incorporated in Case C. Generally through the concept maps, the concepts of sustainability are delivered by incorporating the issues related to environment, economic, systemic approach and empowerment of engineer. Figure 7.32 depicts the conceptual maps of Case C based on the interpretation of the researcher on the documented learning objectives. The data then were calculated for index values which are presented in Table 7.16. All categories that are coded in the conceptual maps are valued as 1.

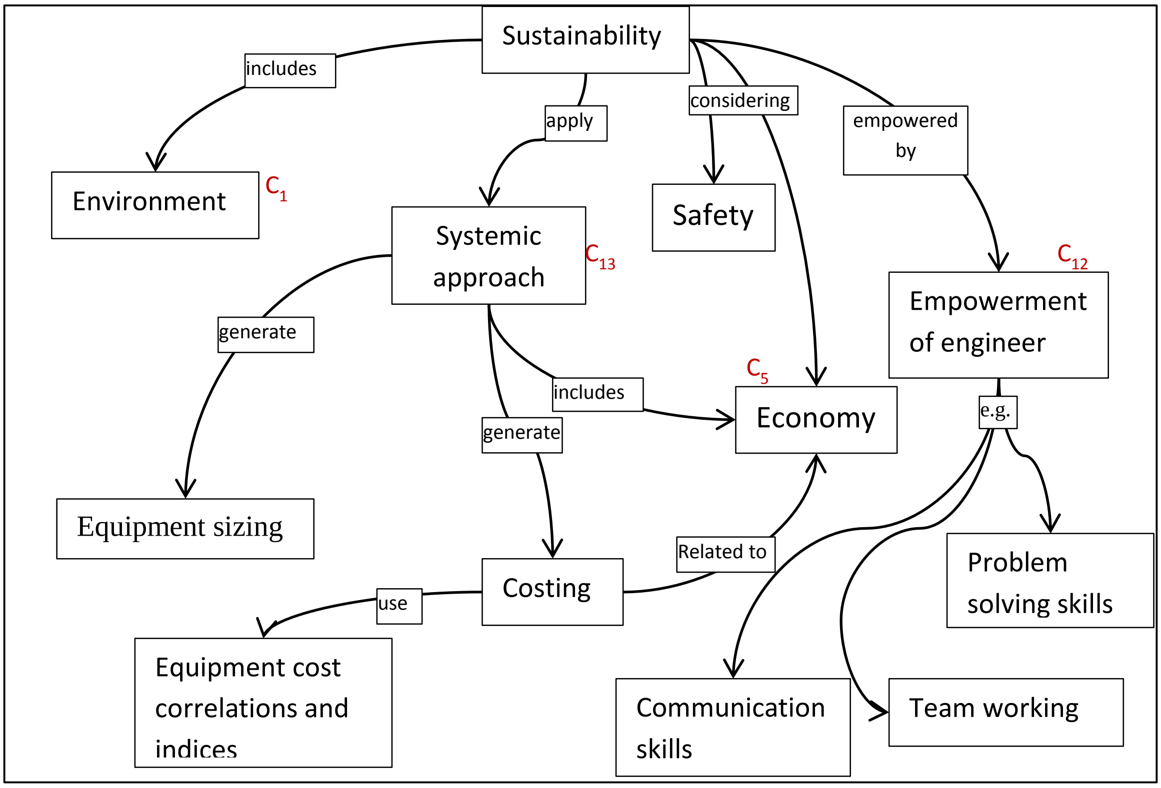


Figure 7.32 Sustainability knowledge documented in Case C

Table 7.16 Index values for Case C

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Response	1	0	0	0	1	0	0	0	0	0	0	1	0	1	0
Index of C_i (i=1-15)	1	0	0	0	1	0	0	0	0	0	0	1	0	1	0

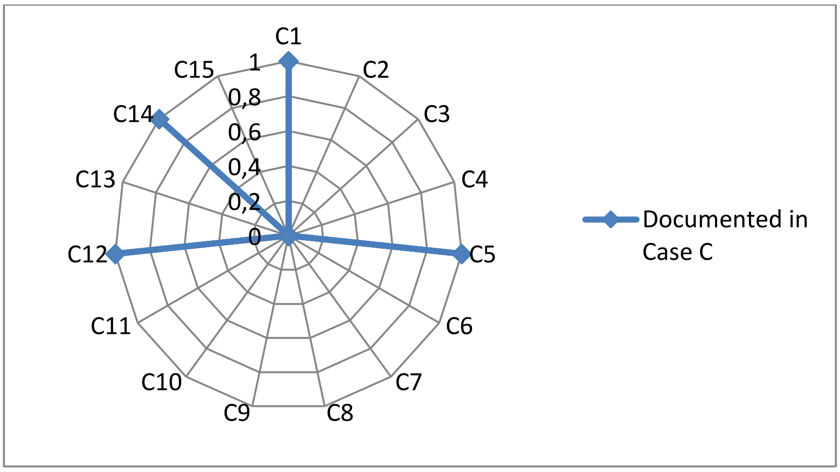


Figure 7.33 Sustainability knowledge documented in Case C

Teacher´s concept maps

Unlike C-Maps prepared by the teacher for Case A and Case B, the C-Maps illustrated in Figure 7.34 are more complex and comprise all components of sustainability. It explains that Case C incorporated fifteen components of sustainability in their engineering curricula. It also indicates that the teacher expected the students to gain knowledge of all components of sustainability.

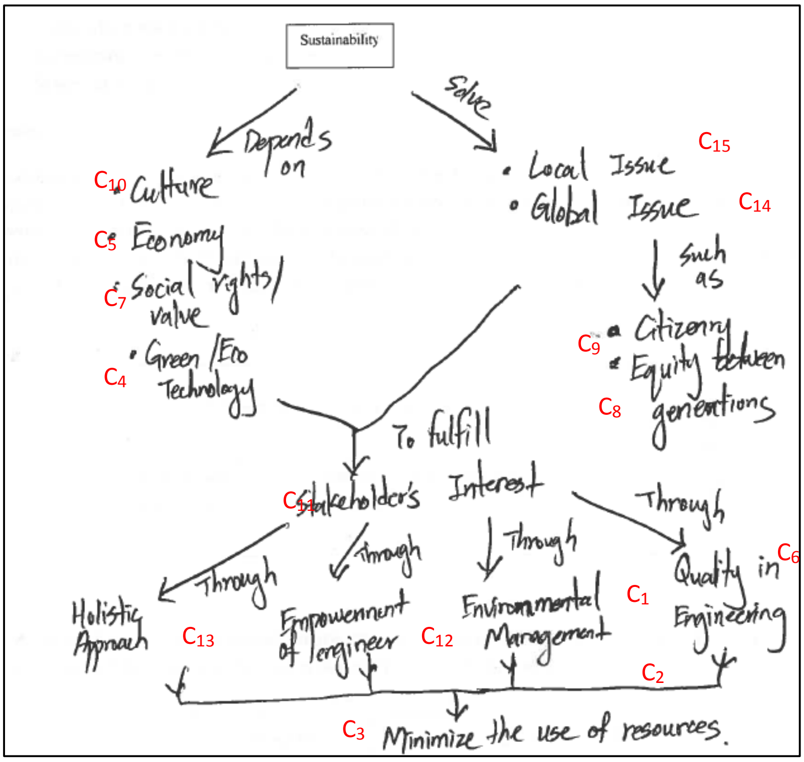


Figure 7.34 Conceptual maps drawn by teacher I3C3

Table 7.17 Index value for each category (C-Maps from course C)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Response	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Index of C_i $_{(i=1\text{-}15)}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

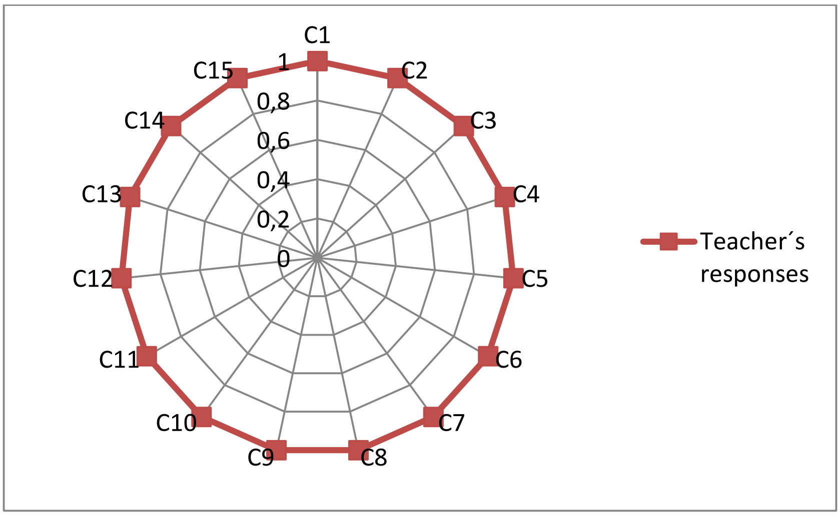


Figure 7.35 Sustainability knowledge provided in Case C

The indicator on the other hand illustrates a different outcome for Case C. The teacher for this particular case expected that at the end of the course the students are able to obtain knowledge of sustainability in all categories. The outcome in a way explains the capability of engineering project to incorporate sustainability and it also reflects the learning objectives of the course. However, the indicator does not explain the cognitive levels (based on Bloom´s taxonomy) of the knowledge needed for students to achieve.

Teacher´s procedural diagram

The outcomes from the procedural diagram in Figure 7.36 shows that students are expected to gain skills in all four phases; the analysis, the design, the development, and the evaluation phases. It also shows that the teacher provided skills which are in category C_1, C_5, C_6, C_{12} and C_{13}.

Table 7.8 shows that the skills were administered according to its relevance to the category. The total score of each category was calculated by summing up the skill scores and the values were carried forward to be the input in calculating the index values (see Chapter 4). Note that the index value for unrelated categories for this course is 0 and the index value for C_1, C_5 and C_{13} is 0.9, and the index value for C_6 and C_{12} is 0.8.

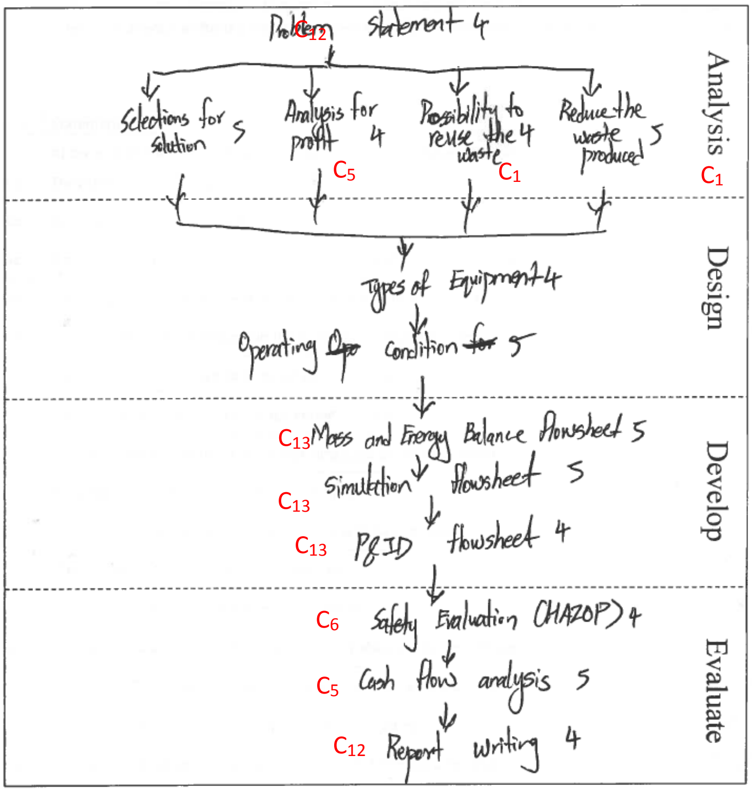


Figure 7.36 Procedural diagrams drawn by teacher I3C3

Table 7.18 Categories of the skills stated by teacher I3C3

Skill	Score	Total score	Category
(Making) a problem statement	3	6	C12
Report writing	3		
Analysis for profit	3	7	C5
Cash flow analysis	4		
Possibility to reuse the waste	3	7	C1
Reduce the waste product	4		
Safety evaluation	3	3	C6
Mass and Energy balance flow sheet	4	11	C13
Simulation flow sheet	4		
P&ID flowsheet	3		

Table 7.19 Index value for each category (PD from Case C)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Score	7	0	0	0	7	3	0	0	0	0	0	6	11	0	0
MSi(PD)	3,5	0	0	0	3,5	3	0	0	0	0	0	3	3,7	0	0
Index of C_i (i=1-15)	0,9	0	0	0	0,9	0,8	0	0	0	0	0	0,8	0,9	0	0

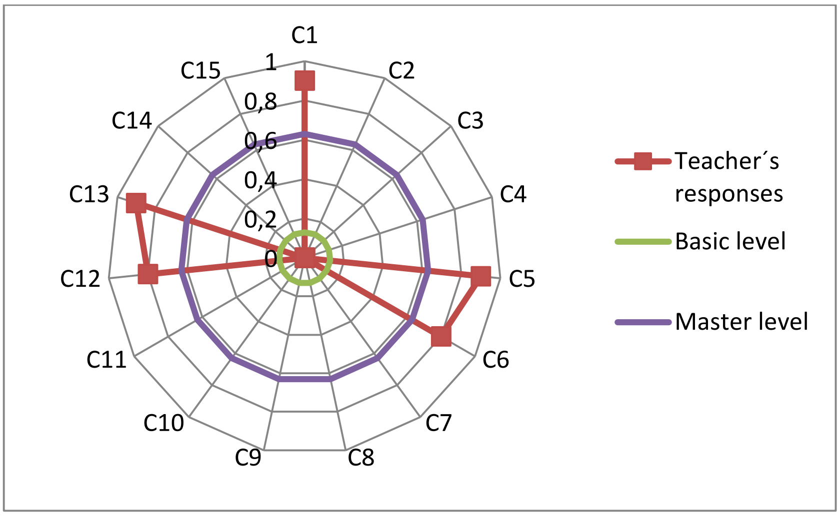


Figure 7.37 Sustainability skills provided for course C

There are five skills provided in Case C. The indicator illustrates that the skills in environmental management, economic, quality in engineering, empowerment of engineer and systemic approach are provided up to master level. It is also predetermined that at the end of the course the students are able to apply the skills on complex tasks. Besides, the results show that the learning objectives are aligned with the accreditation requirements where graduate engineers are expected to design solutions for complex engineering problems and design systems.

Teacher´s feedbacks on the questionnaire

Different with findings in Case A and Case B; the findings from course C demonstrate that the teacher expected the students to have strong positive responses on sustainability. Except for index value for "stakeholders" category (C11), all the categories have an index value of either 0.9 or 1.0.

Table 7.20 Index value for each category (Attitude survey from course C)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Score	10	9	5	5	9	5	10	14	10	5	4	9	9	9	9
MSi(Att)	5	4,5	5	5	4,5	5	5	4,7	5	5	4	4,5	4,5	4,5	4,5
Index of C_i $_{(i=1\text{-}15)}$	1	0,9	1	1	0,9	1	1	0,9	1	1	0,8	0,9	0,9	0,9	0,9

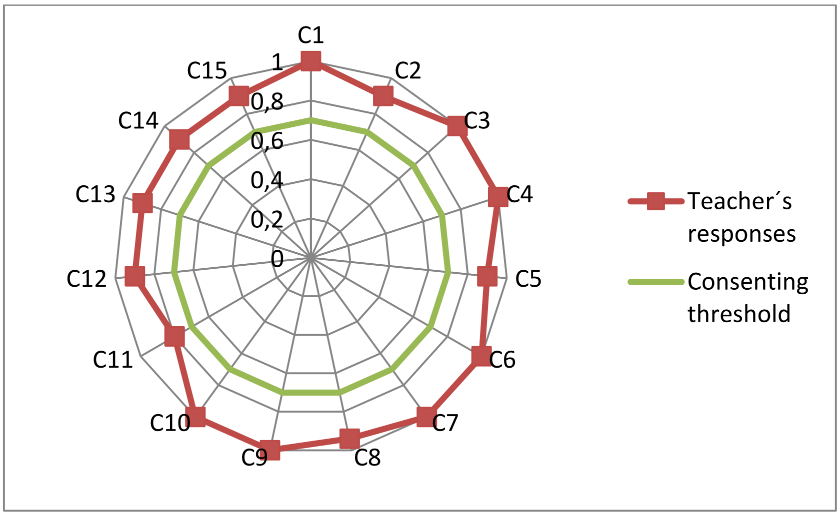


Figure 7.38 Sustainability attitude provided for course C

Students´ conceptual maps

The following figures in this section show three examples of students´ conceptual maps from Case C. By comparing conceptual maps drawn by students from the other two cases, the conceptual maps are complex in terms of its connection between the key concepts. The provided key concepts also include almost all fifteen components of sustainability in engineering education. These results could reflect the ability of the students in understanding the concepts of sustainability and reflect the knowledge of sustainability provided in Case C.

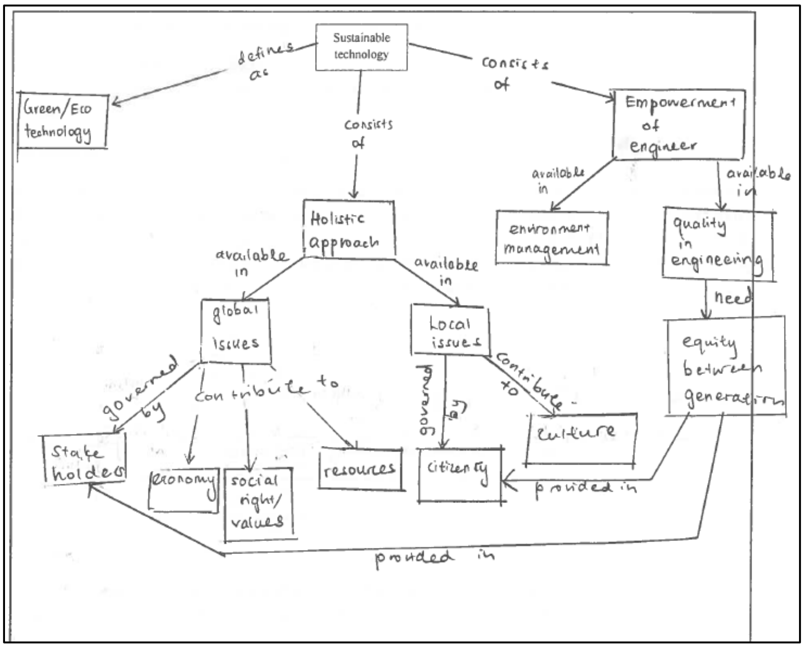


Figure 7.39 Conceptual maps drawn by student I2C3R2

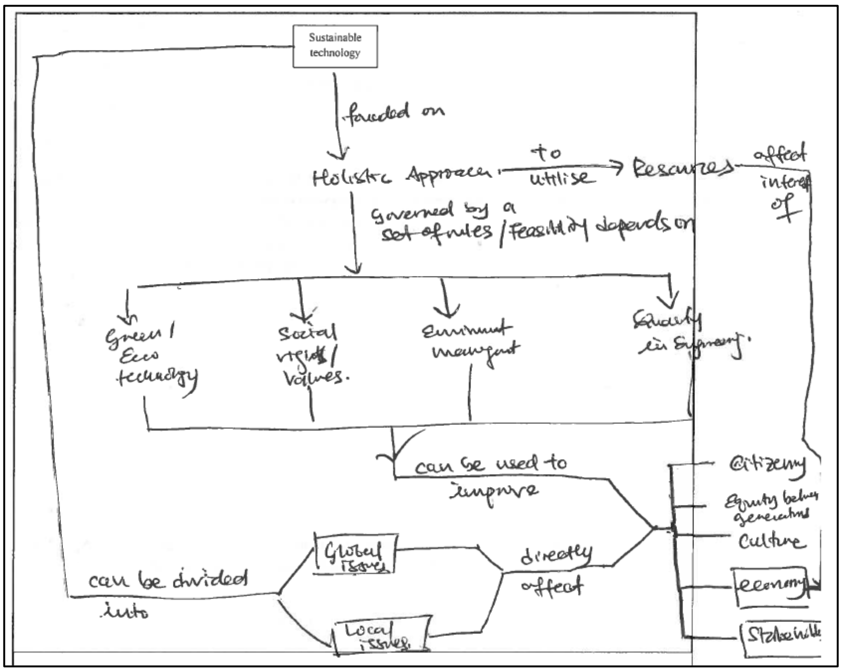


Figure 7.40 Conceptual maps drawn by student I2C3R4

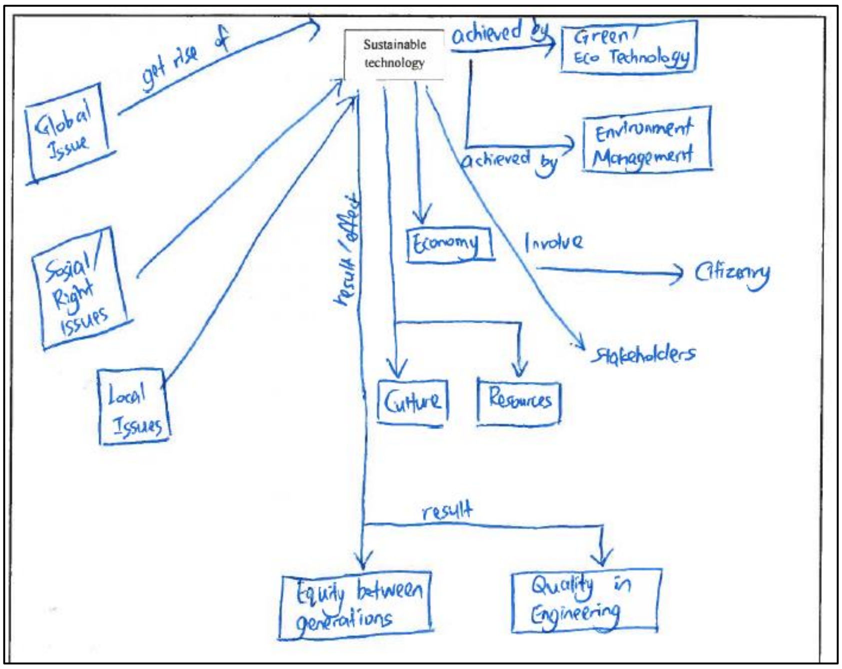


Figure 7.41 Conceptual maps drawn by student I2C3R12

Table 7.21 Index value for each category (Students´ C-Maps from Case C)

Respondent	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	% C_i
$I_2C_3R_1$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_3R_2$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_3R_3$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_3R_4$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_3R_5$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_3R_6$	1	1		1		1	1	1		1		1		1	1	67
$I_2C_3R_7$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_3R_8$	1	1	1	1		1	1	1		1	1		1	1	1	80
$I_2C_3R_9$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_3R_{10}$	1		1	1	1	1			1	1	1		1			60
$I_2C_3R_{11}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_3R_{12}$	1	1	1	1	1	1	1	1	1	1	1			1	1	87
$I_2C_3R_{13}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_3R_{14}$	1	1	1	1	1	1	1	1	1	1	1	1		1	1	93
$I_2C_3R_{15}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_3R_{16}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_3R_{17}$	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100
$I_2C_3R_{18}$	1	1	1	1	1	1		1	1	1	1	1	1	1	1	93
$I_2C_3R_{19}$	1	1	1	1	1	1		1	1	1	1	1	1	1	1	93
$I_2C_3R_{20}$	1	1	1	1	1	1		1	1	1	1	1	1	1	1	93
Total score of C_i (i=1-15)	20	19	19	20	18	20	16	19	18	20	19	17	17	19	19	
Samples N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	
Index of C_i (i=1-15)	1,0	1,0	1,0	1,0	0,9	1,0	0,8	1,0	0,9	1,0	1,0	0,9	0,9	1,0	1,0	

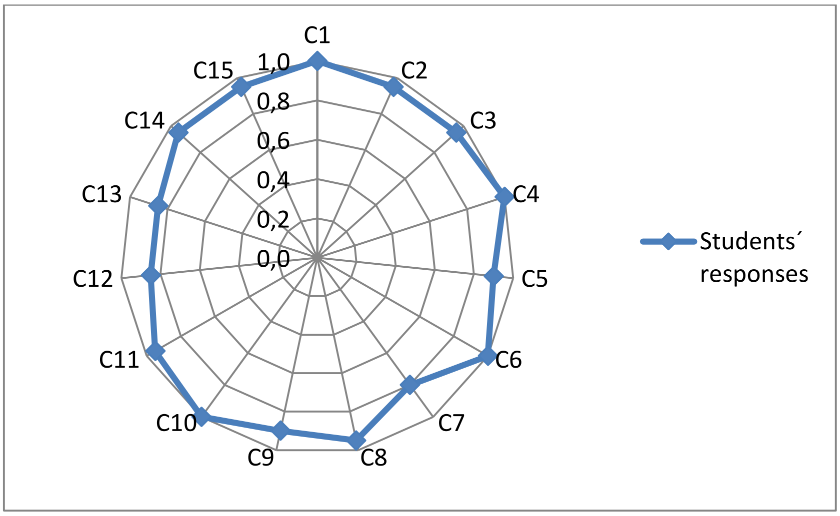


Figure 7.42 Sustainability knowledge obtain in Case C

The analysis on the Table 7.21 is an evident of the fact that 90% of the students is able to connect more than 80% of the sustainability components to the concept of sustainable technology. The indicator from Figure 7.42 also propagates the mutual understanding on the concept of sustainable technology which is related to the area of environmental management, environmental assessments, resources prevention, green/eco technology, quality in engineering, equity between generations, culture, stakeholders, global and local issues.

Students´ procedural diagrams

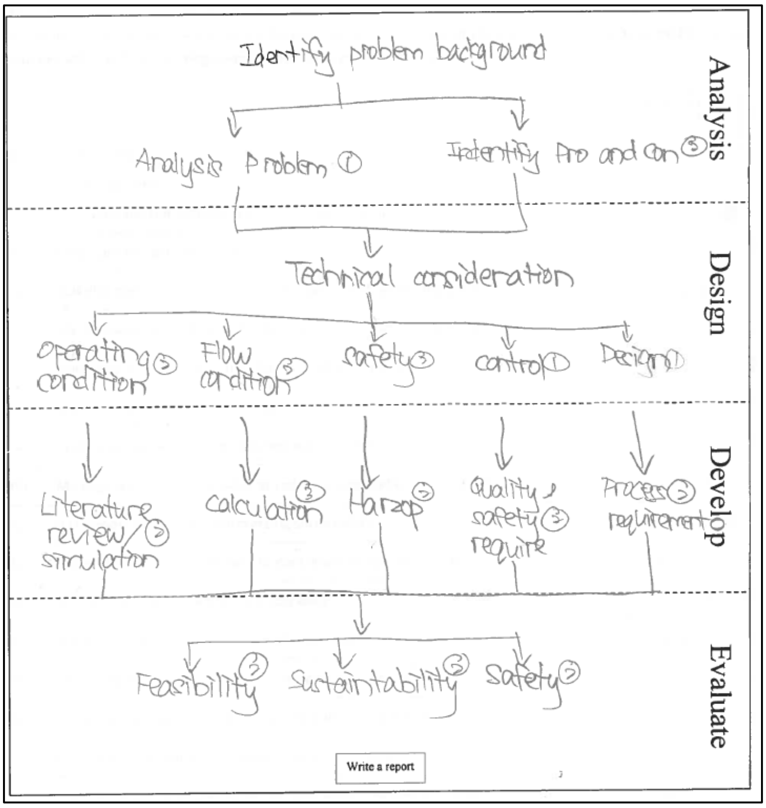


Figure 7.43 Procedural diagrams drawn by student I2C3R1

Figure 7.43, Figure 7.44 and Figure 7.45 depict another evident of the use of procedural diagrams and self-rate procedures in assessing sustainability skills amongst students. From the figures, the it is observed that the students are able to build procedural diagrams on several skills that are required in producing sustainable technology and clearly the skills have been mentioned in the diagrams. The students also have shown their ability to rate themselves using five-point score (see Table 4.4). From these scores, the researcher is able to identify the level of the skills obtained by the students in Case C.

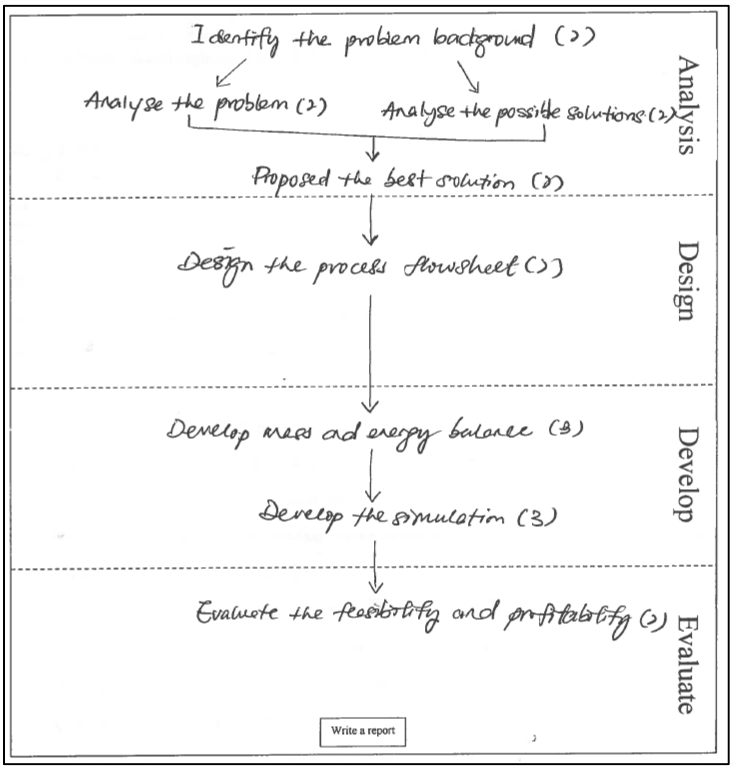


Figure 7.44 Procedural diagrams drawn by student I2C3R3

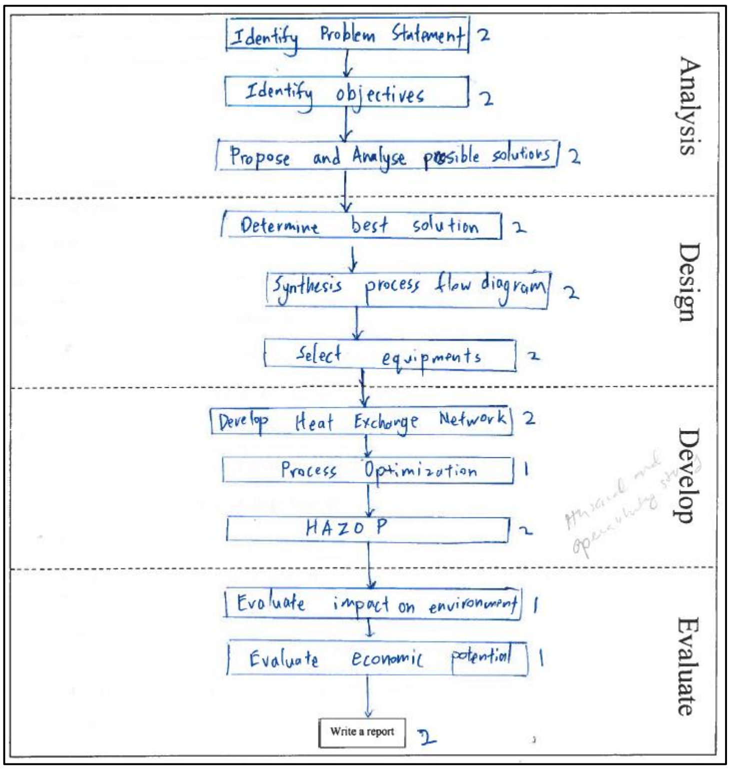


Figure 7.45 Procedural diagrams drawn by student I2C3R7

Table 7.22 Index value for each category (Students´ PD from Case C)

Respondent	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
$I_2C_3R_1$		2				2	2					1,5			
$I_2C_3R_2$															
$I_2C_3R_3$					2	2						2			
$I_2C_3R_4$						3						3,5	4		
$I_2C_3R_5$					2	3						2			
$I_2C_3R_6$												3	2		
$I_2C_3R_7$		1			1							2	2		
$I_2C_3R_8$															
$I_2C_3R_9$															
$I_2C_3R_{10}$															
$I_2C_3R_{11}$					3	3						3			
$I_2C_3R_{12}$															
$I_2C_3R_{13}$															
$I_2C_3R_{14}$															
$I_2C_3R_{15}$															
$I_2C_3R_{16}$					3							3	3		
$I_2C_3R_{17}$															
$I_2C_3R_{18}$					2							2	2		
$I_2C_3R_{19}$					3							2			
$I_2C_3R_{20}$					3							2	3		
Total score of $C_{i\ (i=1\text{-}15)}$	0	3	0	0	19	13	2	0	0	0	0	26	16	0	0
Samples N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Index of C_i (i=1-15)	0	0,1	0	0	0,4	0,3	0,0	0	0	0	0	0,5	0,3	0	0

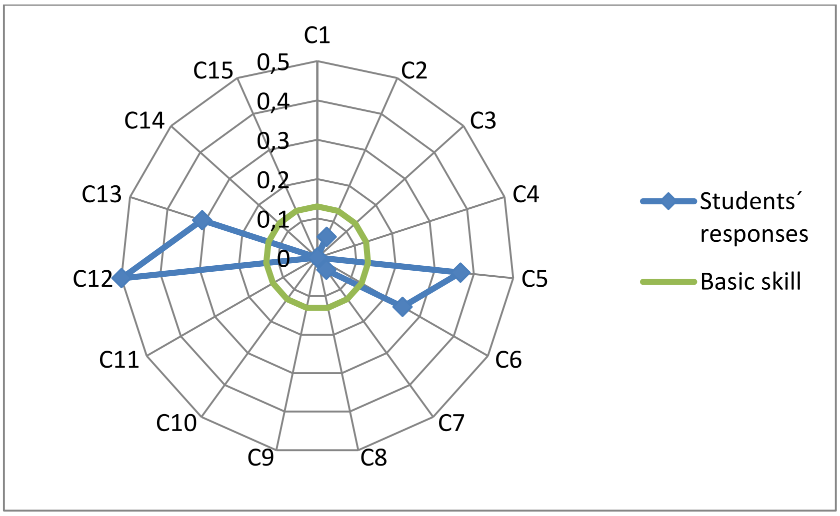


Figure 7.46 Sustainability skills obtained in Case C

With a 55% response rate, the obtained sustainability skills have been analysed in terms of its average scores and index values. From the analysis, the researcher transformed the data into the indicator. Figure 7.46 depicts four sustainability skills are plotted outside the basic skill circle (green circle). It indicates that the sustainability skills related to the area of economic

(C5), quality in engineering (C6), empowerment of engineer (C12) and holistic/systematic approach (C13) obtained by the students are at least at basic skill. In fact, the indicator has indicated that the students are experienced in applying the skills related to economic and empowerment of engineer on difficult task (index value in range 0.38 to 0.62).

Students´ feedbacks on the questionnaire

Table 7.23 Index value for each category (Students´ feedbacks from Case C)

Respondent	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
$I_2C_3R_1$	5	3	5	5	3,5	5	4,5	4,3	5	5	3	4,5	5	3,5	5
$I_2C_3R_2$	5	3	5	5	5	5	5	5,0	5	5	5	5	5	4,5	5
$I_2C_3R_3$	4,5	5	5	5	4,5	5	5	5,0	4,5	5	4	4,5	5	4,5	4,5
$I_2C_3R_4$	4,5	5	5	5	5	5	5	5,0	5	5	4	4	4	5	5
$I_2C_3R_5$	5	4,5	5	5	4	5	5	5,0	5	4	5	4	4,5	5	5
$I_2C_3R_6$	4	4,5	5	5	3,5	5	3,5	2,7	4	4	4	4,5	3,5	3,5	3,5
$I_2C_3R_7$	4	4,5	5	5	4	5	4,5	3,0	4,5	4	4	4,5	4,5	4	4
$I_2C_3R_8$	3	3	4	4	4	4	3,5	3,0	4	3	3	4	3,5	3	4
$I_2C_3R_9$	3	4	3	3	3,5	4	3,5	3,3	4	3	3	3	3	4	4
$I_2C_3R_{10}$	4,5	4,5	3	5	4	4	3	3,7	4	4	3	4	3,5	4,5	4
$I_2C_3R_{11}$	4,5	4	5	4	4	5	3	3,7	5	5	5	5	3,5	4,5	3,5
$I_2C_3R_{12}$	4,5	4,5	4	4	5	4	4,5	4,3	4	4	4	4,5	4	4	5
$I_2C_3R_{13}$	2,5	2,5	4	3	2,5	3	4	3,7	3	4	3	3	2,5	2,5	3
$I_2C_3R_{14}$	4	3,5	4	4	3,5	4	4	3,7	4	3	4	3	3,5	4	4
$I_2C_3R_{15}$	3	3,5	3	4	3	3	2,5	3,0	4	3	2	3	3	2,5	3
$I_2C_3R_{16}$	5	4,5	5	4	5	5	4,5	4,3	5	5	5	4,5	4,5	5	4,5
$I_2C_3R_{17}$	3,5	3,5	4	4	3,5	4	4	3,3	4	4	4	3,5	3,5	4	4
$I_2C_3R_{18}$	3,5	3,5	4	3	4,5	4	3,5	4,3	3,5	3	4	4	4,5	4,5	4,5
$I_2C_3R_{19}$	4,5	5	5	5	5	5	4,5	4,7	5	5	5	5	4,5	5	4,5
$I_2C_3R_{20}$	4	4	5	5	4	4	4	4,0	4	4	3	4	4	4	4,5
Average of C_i $_{(i=1\text{-}15)}$	4,1	4,0	4,4	4,4	4,1	4,4	4,1	4,0	4,3	4,1	3,9	4,1	4,0	4,1	4,2
Samples N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Index of $C_{i\ (i=1\text{-}15)}$	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,9	0,8	0,8	0,8	0,8	0,8	0,8

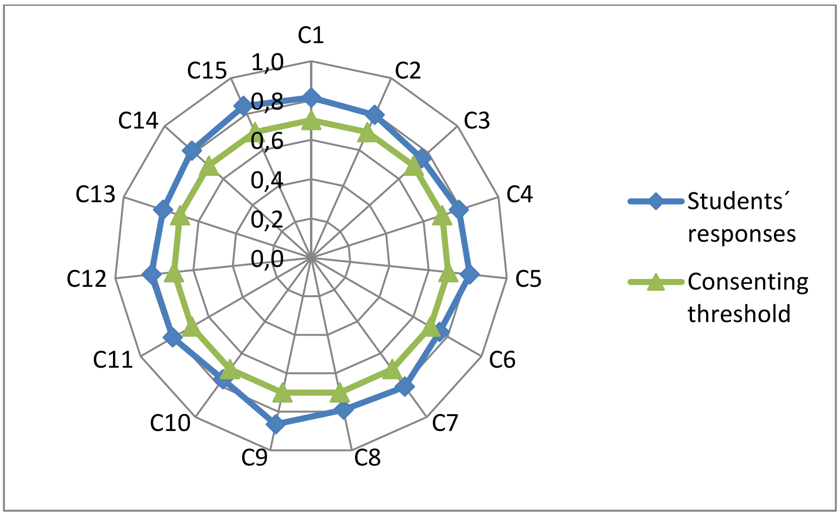


Figure 7.47 Sustainability attitudes obtained in Case C

From the analysis of 20 students´ feedbacks on the questionnaires, the researcher has calculated the scores of items in terms of its average scores and index values. The attitudes of students towards sustainability can be interpreted through the indicator presented in Figure 7.47. The figure shows that with a value in the range from 0.7 to 0.89, all students have learnt to agree that as future engineers they are responsible for sustainability in many aspects that comprise 15 components. They also have shown their strong agreement on the aspect of citizenry.

7.4. Evaluating the effectiveness

In this part of analysis, the study presents the effectiveness of the cases by comparing teacher´s responses and students´ responses in terms of sustainability knowledge, skills and attitudes. The presentations are based on the results depicted by the indicator which has been developed for this purpose. The indicator has the ability to show the index values (indication of sustainability knowledge, skills and attitudes in the form of index values) and to categorize the responses into three major pillars of sustainability (environmental pillar, economic pillar and social pillar).

7.4.1. Case A

Sustainability knowledge

Figure 7.48 depicts that there are only five categories mentioned as a part of the learning objectives for Case A. Most of the categories focus on the issues of environment. However, the indicator shows that the teacher expected **all** students to be able to connect all categories (all three pillars) with the concept of sustainability (except C8) and the result shows **majority** (index value between 0.6 and 0.9) of the students are at least able to connect all categories (except C10) with the concept of sustainability.

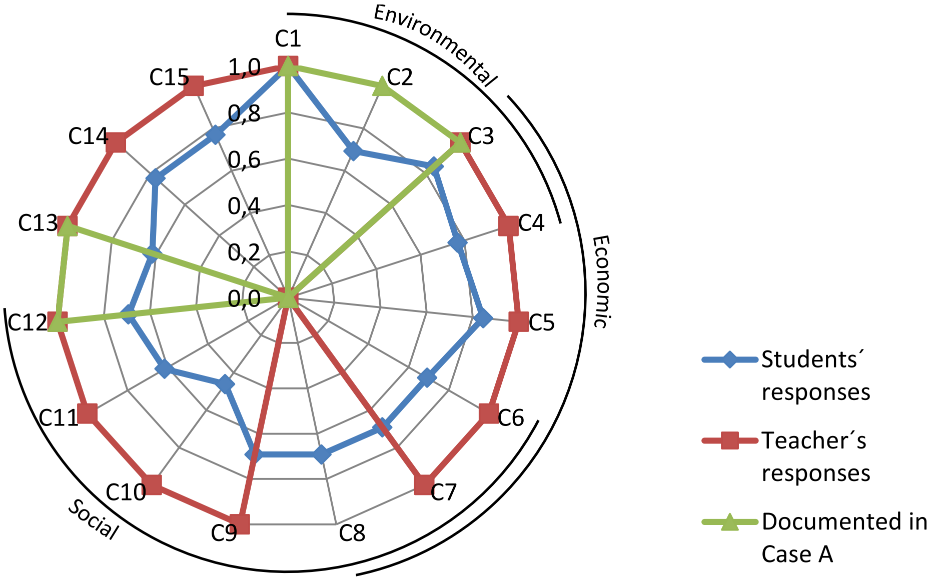


Figure 7.48 Case A – Effectiveness of learning sustainability knowledge

Sustainability skills

The following figure indicates that there are several skills obtained by the students even though the teacher of this case did not expect any skills to be acquired. In fact, the indicator shows that the students obtained the basic level for the skill that is categorized in the social pillar (C12) and C13.

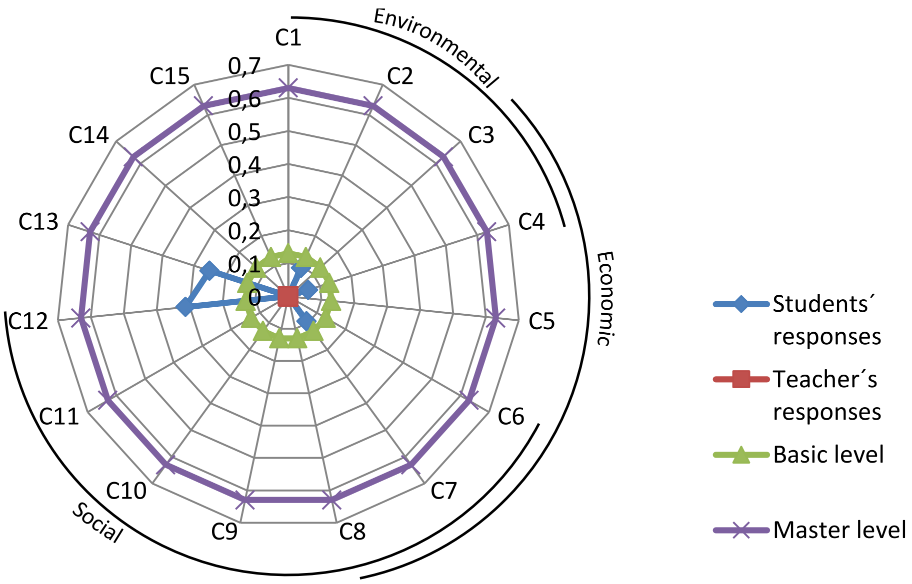


Figure 7.49 Case A – Effectiveness of learning sustainability skills

Sustainability attitudes

In the aspect of attitudes towards sustainability, the indicator shows that the students´ have equal or more positive levels of agreement (based on index values) except for C5 (economic category). The indicator also shows that the students are still gaining positive attitudes towards some categories even though the teacher believed it has been under-represented. It explains that the students have attained positive attitudes towards all categories slightly higher than expected.

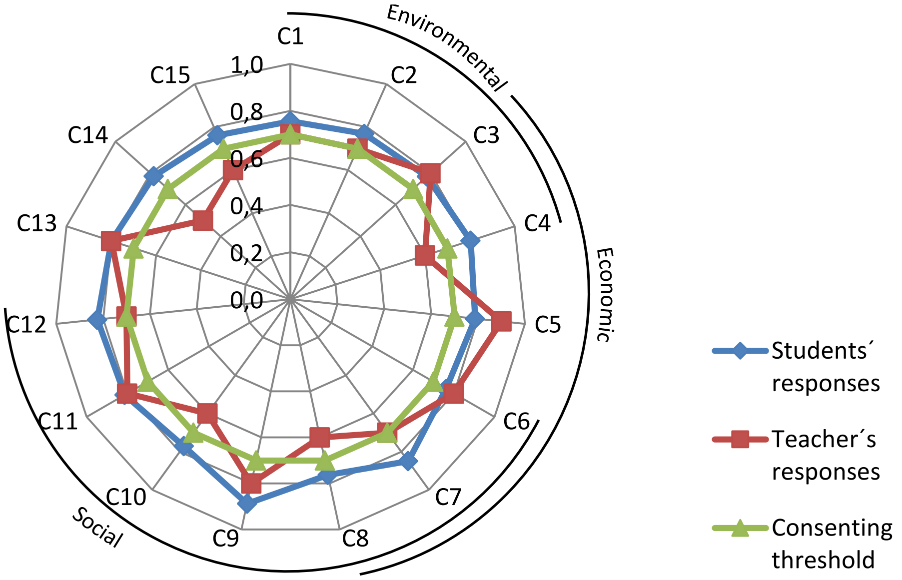


Figure 7.50 Case A – Effectiveness of learning sustainability attitudes

7.4.2. Case B

Sustainability knowledge

For case B, figure 7.51 indicates that based on the documented learning objectives, the course focuses on environment pillar with some aspects in economic and social pillars. Similarly, the teacher expected the students to have the ability to connect some categories in the environment pillar to the concept of sustainability. However, the results show that majority (index value between 0.6 – 0.9) of the students are able to connect all categories (regardless of its pillars) to the concept of sustainability.

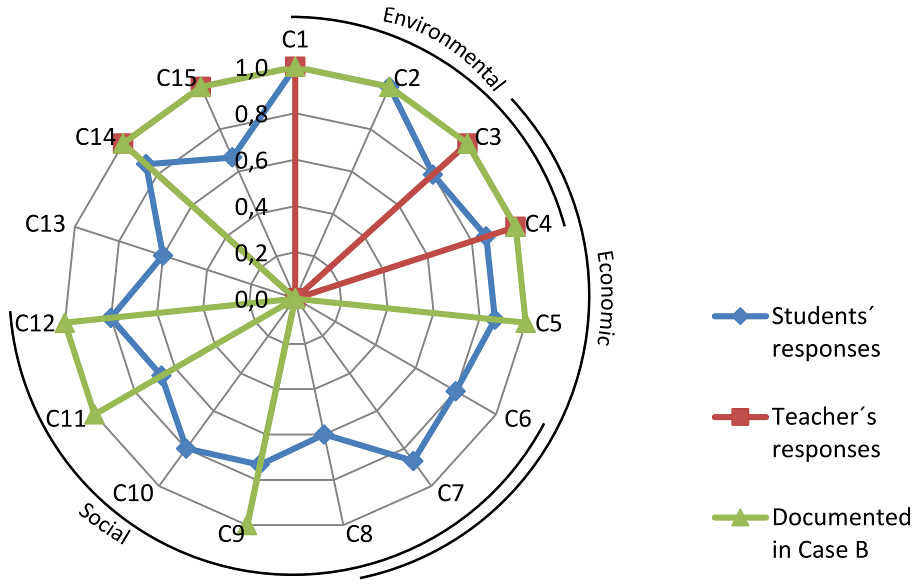


Figure 7.51 Case B – Effectiveness of learning sustainability knowledge

Sustainability skills

In the following figure, the indicator depicts that there are several sustainability skills obtained by the students and some of them surpass the basic skill level. This is a contradicting result from the teacher´s responses where there is only one sustainability skill (C12) expected to be acquired by the students. In fact, the students indicated that they obtained the sustainability skill (C12) and are reaching to the master level (experienced in applying the skill on complex task).

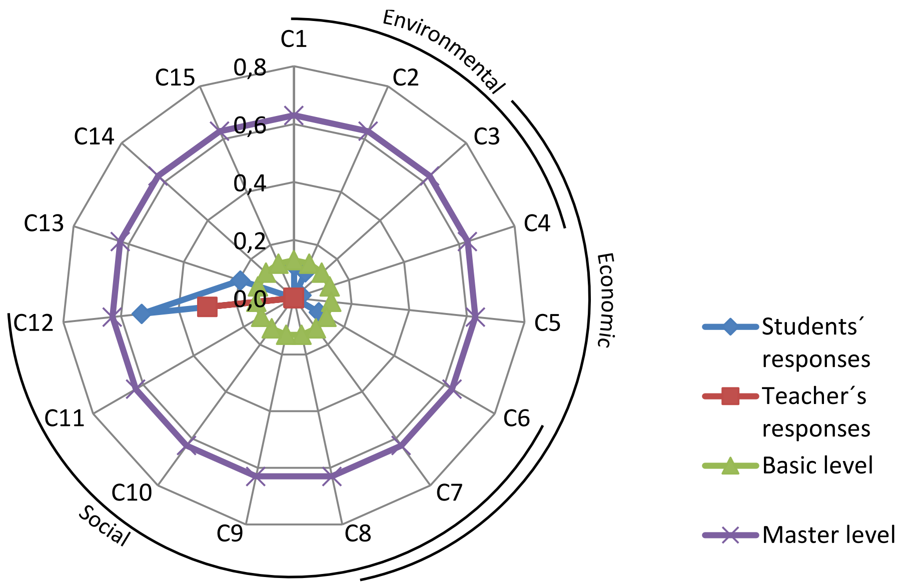


Figure 7.52 Case B – Effectiveness of learning sustainability skills

Sustainability attitudes

Figure 7.53 describes in radar graph representation of the comparison between expectation of the teacher and the students´ attitude towards the concept of sustainability. Obviously from the graph, the teacher expected the students to have a positive attitude on all fifteen categories in the concept of sustainability. The result shows that even though the index values for students´ attitude are slightly lower than what are expected, the students are still gaining positive attitude in all categories. This is due to the fact that the index values for students´ responses have surpassed the consenting threshold line.

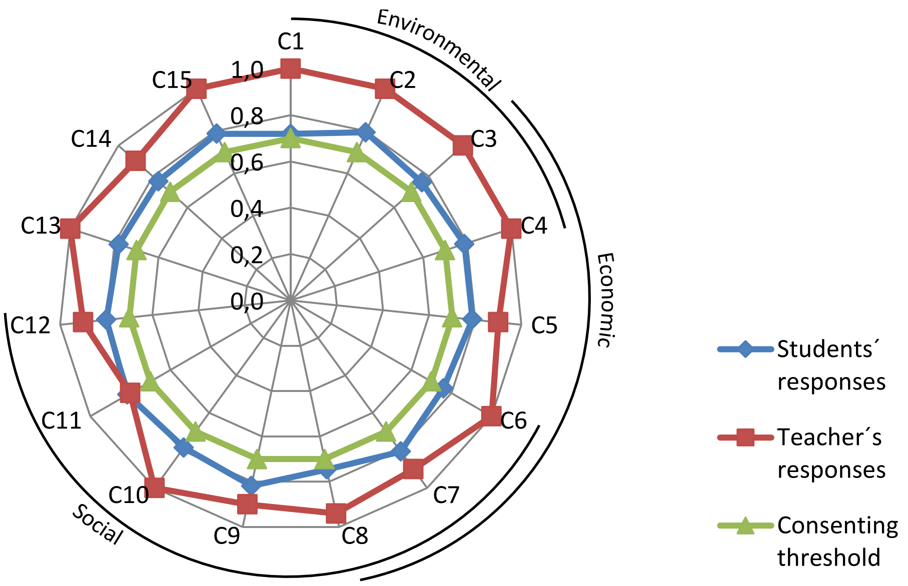


Figure 7.53 Case B – Effectiveness of learning sustainability attitudes

7.4.3.Case C

Sustainability knowledge

Based on the documented learning objectives in Case C, there are only four categories that have been connected to the concept of sustainability. In contrast, the results from teacher´s responses and students´ responses show that i) it is expected by the teacher that, at the end of the course (Case C), the students are able to connect all categories (except C2) with the concept of sustainability and ii) all students are able to connect majority of the categories with the concept of sustainability. By comparison between teacher´s responses and students´ responses there is only a small number of students (due to a small a difference between index values in the same category) that couldn´t relate some categories with sustainability concept.

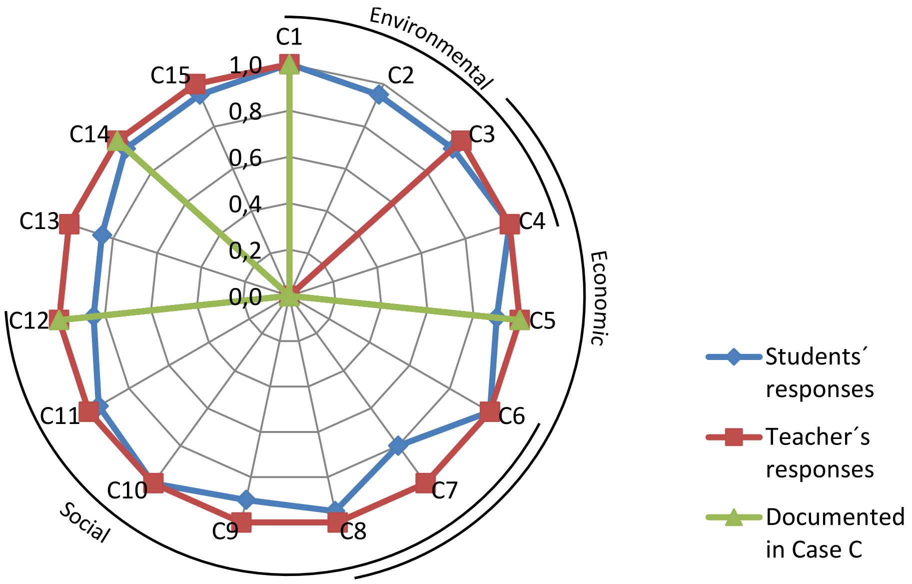


Figure 7.54 Case C – Effectiveness of learning sustainability knowledge

Sustainability skills

From figure 7.55, there are five categories of sustainability skills that are expected by the teachers for students to obtain. Two of the skills are related to economic pillar, one is related to environment pillar and another one is related to social pillar. All sustainability skills are indicated to be higher than master level. On the other hand, students assessed their sustainability skills as slightly higher than the basic level for four categories and below basic level for C1.

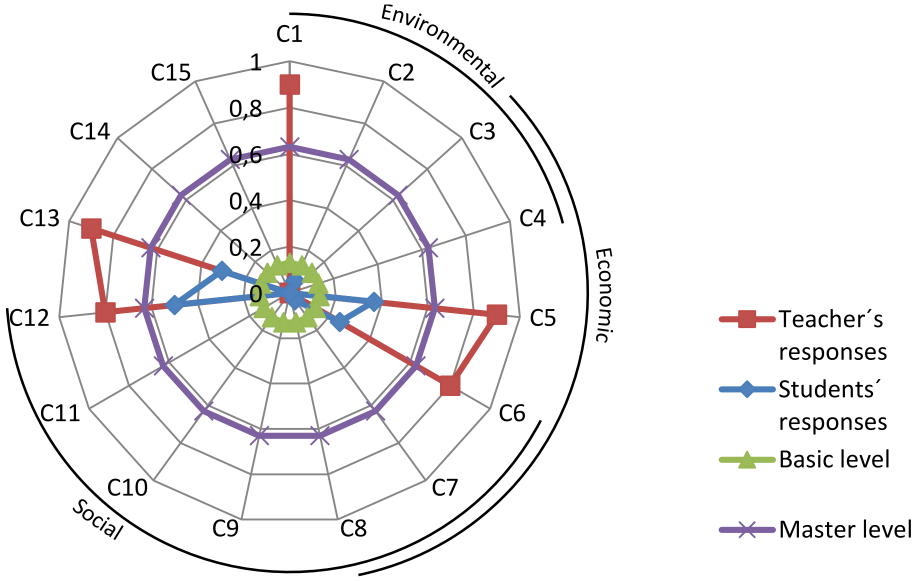


Figure 7.55 Case C – Effectiveness of learning sustainability skills

Sustainability attitudes

In the aspect of sustainability attitudes, the following figure shows that both teacher´s responses and students´ responses are indicated higher than the consenting threshold line. By a small number of difference between index values in the same categories, both the teacher and students have positive attitudes towards sustainability for all categories.

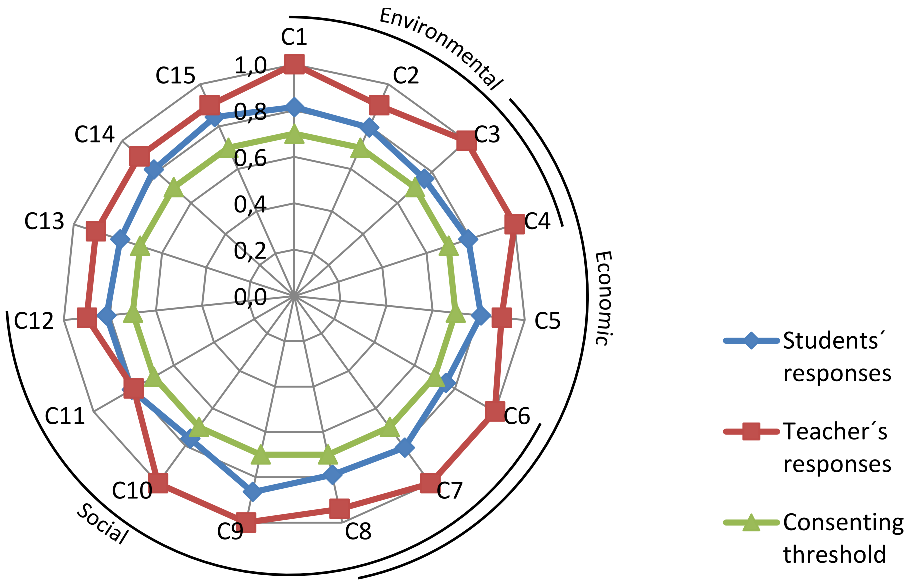


Figure 7.56 Case C – Effectiveness of learning sustainability attitudes

7.5. Analysing the factors that contribute to the effectiveness

Previously in Chapter 4, the instrument and the method used to identify the factors that contribute to the effectiveness of the three cases have been explained. Analysis of data taken from self-administered close-ended questionnaires (please refer to Appendix F) is based on i) role of teacher, ii) role of student, iii) role of learning environment, iv) role of learning materials and v) role of environment. From the analysis, the study can identify the factors and connect the research outcomes with the practiced teaching and learning activities of the cases. Therefore, the research outcomes do not only present the factors but also highlight the teaching and learning activities that give high impacts to the learning of sustainability in engineering education.

Case A

Case A is an engineering course that provides understanding on engineering as a field of discipline and professions. This course also provides understanding on the concept of sustainability and its relation to engineering. The following table presents the comparison between course plan, learning objectives for the learning of sustainability, learning outcomes and factors that contribute to students learning outcomes. It shows that the role of teacher to determine the knowledge for learning is important to drive the learning of sustainability. The role of teacher in contributing the learning of sustainability is clearly not reflecting the issues of sustainability that have been incorporated in the documented learning objectives, but it reflects the strategies taken for teaching and learning, learning materials and students activities.

Table 7.24 Summary of Case A

Course plan	Learning objectives for learning of sustainability	Learning outcomes (evaluation)	Factors that contribute to students learning outcomes
Learning objectives: • Issues of sustainability are incorporated in some of the existing learning objectives. Teaching and learning strategies: • Lectures • Problem based learning • Industrial visits • A competition Students activities: • Peer teaching • Communicating to community of practice Learning materials: • Course materials • Case studies Assessment techniques: • Formative – Project presentations • Summative – Project reports	Knowledge: • Focuses on environmental issues • Some aspect on social issues • Includes systemic approach on problem solving Skills: • None Attitude: • Positive attitudes towards some issues in sustainability	Knowledge: • High percentages of students are able to connect environmental issues to sustainability concept • Majority of students are able to connect the three pillars to sustainability Skills: • Acquired basic level of “social” skills Attitude: • Majority of students have positive attitudes towards all issues in sustainability	Role of teacher: • Determine the knowledge for learning Role of student: • Contribute in group´s project Learning environment: • Listen to the lecture • Participate in group´s project Learning materials: • Case studies • Several people Environment: • Classroom

The results also show the contribution of active learning such as group project, case studies and communicating to several people as one of the major factors to students learning outcomes. However, one of the active learning activities, which is industrial visit, is considered as less contributing to the students learning outcomes. This is proven by Tables F1, F2, F3 and F4 (see Appendix F), which indicate that the perspectives of students on industrial visit activities are leaned towards disagreement and neutral stands. Therefore, it is a valuable feedback for the teacher to redesign the existing strategies of an industrial visit activity to enhance the impacts of learning (students learning outcomes). The results of the analysis also show that course materials and self-search are the least contributing factors to the students learning outcomes. In other words, the students have learnt the knowledge of sustainability mostly from case studies, seminars and several people.

Case B

Case B is an engineering course that is offered to Civil engineering students. The course provides understanding on the role of engineer for sustainability and the application of the concept in construction. Similar to the research outcomes of Case A, the results from the analysis of Case B also indicate that the major contributor for the students learning outcomes in learning sustainability is from an active learning approach. Factors such as group discussion, group project participation, and communicating with several people in the learning process are evidenced to impact the active learning in understanding concept of sustainability. The table below shows that it has been planned in the course that the students will experience several types of teaching and learning strategies e.g. site visits, community services and research based learning, and participate in several types of learning activities e.g. interviewing sustainability experts, peer teaching, and participating in research development on sustainability. The results show that the students have gained knowledge of sustainability including the other two pillars that are not part of the documented learning objectives, developed several types of skill, and acquired positive attitudes towards all issues related to sustainability. By comparison between the applied teaching and learning strategies, the results in Tables F7, F8, F9 and F10 depict that research based learning positively contributes to the learning of sustainability.

Table 7.25 Summary of Case B

Course plan	Learning objectives for learning of sustainability	Learning outcomes (evaluation)	Factors that contribute to students learning outcomes
Learning objectives: • Issues of sustainability are incorporated in all learning objectives Teaching and learning strategies: • Lectures • Site visits • Community services • Research based learning Students activities: • Interviewing sustainability experts • Communicating to community of practice • Preaching the concepts of sustainability • Participating in research	Knowledge: • Focuses on environmental issues • Includes some issues of social Skills: • Focus on empowering engineer (soft skills) Attitude: • Strongly positive attitudes towards all issues in sustainability	Knowledge: • High percentages of students are able to connect environmental issues to sustainability concept • Majority of students are able to connect the three pillars to sustainability Skills: • Developed skills on several categories of sustainability. • Developed skills in categories of “empowerment of engineer” and “holistic/systematic approach” up to the basic level. Attitude:	Role of teacher: • Determine the knowledge for learning Role of student: • Participate in group discussion • Contribute in group project Learning environment: • Participate in group project • Discussion with friends Learning materials: • Course materials • Several people Environment: • Classroom

development on sustainability Learning materials: • Course materials Assessment techniques: • Formative – Research presentations, exhibitions, feedback questionnaires • Summative – technical papers, reports		• Majority of students have strongly positive attitudes towards all issues in sustainability	

Case C

Case C is another engineering course that incorporates sustainability. Based on the documented learning objectives, the course incorporates only small parts of sustainability concepts. Due to the implementation of project based learning as the approach to learning, the results of the analysis shows the participation of students in discussions and group projects is the factor that contributes to students learning outcomes. The students also indicate that mostly they acquired the knowledge of sustainability through their group project, solving problems and discussion with friends (see Table F 13 in Appendix F). From the following table, the study could assume that the implementation of project based learning contributes to the high percentages of students that are able to connect environmental issues and economic issues to the concepts of sustainability. However, the results from course evaluation show that the students learning outcomes in terms of skills are slightly below than the teacher´s expectation. This is an important result and the reason for teachers in the future to focus on redesigning the learning activities in project based learning (major contributor to the students learning outcomes) so that the students are able to develop their skills up to the expectations.

Table 7.26 Summary of Case C

Course plan	Learning objectives for learning of sustainability	Learning outcomes (evaluation)	Factors that contribute to students learning outcomes
Learning objectives: • Selected topics of sustainability are incorporated in some of the existing learning	Knowledge: • Very limited to specific issues Skills: • Mastering some skills related to	Knowledge: • High percentages of students are able to connect environmental issues and	Role of teacher: • Outlined the knowledge for learning with some flexibility Role of student:

objectives Teaching and learning strategies: • Lectures • Project based learning Students activities: • Participating in group projects Learning materials: • Course materials Assessment techniques: • Formative – group presentations • Summative – reports	economy and environmental management • Includes mastering skills related to empowerment of engineer and holistic/systemic approach Attitude: • Positive attitudes towards all sustainability issues	economic issues to sustainability concept • Majority of students are able to connect the three pillars to sustainability Skills: • Developed skills related to economy up to the basic level • Developed skills related to empowerment of engineer and holistic/systemic approach up to the basic level Attitude: • Positive attitudes towards all sustainability issues	• Participate in group discussion • Contribute in group project Learning environment: • Group project • Problem solving • Group discussion Learning materials: • Course materials • Case studies Environment: • Classroom • Discussion room

7.6. Conclusion – Inputs to design a framework: Incorporating sustainability in course planning

This chapter has presented the analysis processes and the research outcomes on the evaluation of course effectiveness for sustainability incorporation. The effectiveness of three cases were presented by comparing students learning outcomes and course learning objectives in terms of knowledge, skills and attitudes. The alignment of course plan, learning objectives for learning of sustainability, learning outcomes and the factors that contribute to students learning outcomes were also presented. Based on the empirical studies from phase 1, phase 2 and phase 3, this study can highlight that there are five elements of curriculum design for sustainability incorporation.

The elements are:

i) Learning objectives
ii) Teaching and learning approaches
iii) Learning activities
iv) Learning materials
v) Assessment methods

Generally, the incorporation of sustainability into the existing engineering curricula can be illustrated into the following figure. The incorporation demands changes in all five elements of curriculum design. Each of the changed elements has to be aligned to other elements. However the elements of curriculum design presented in the general concept of sustainability incorporation is not rigid in terms of its sequence. In other words, `learning objectives´ is not always on the top of the sequence and `assessment methods´ is not always at the bottom. The sequence of the elements is rather depending on the employed curriculum model.

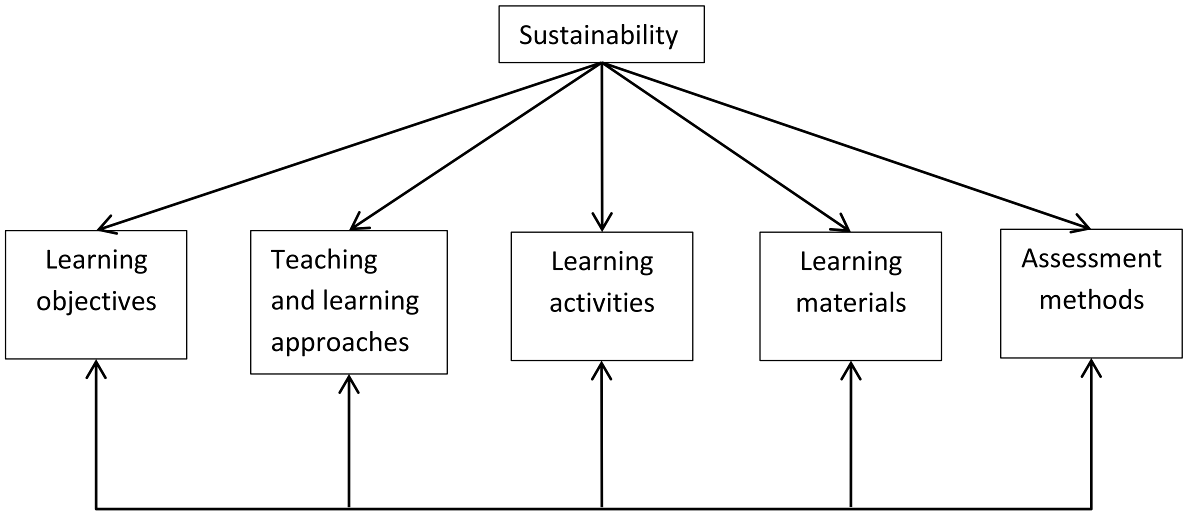


Figure 7.57 General concept of sustainability incorporation

In the study of the three cases (Case A, B and C), the engineering curricula were developed on the basis of a constructive alignment model. It is a model where learning objectives are the main references to develop and construct other elements of the curriculum. Therefore, in the effort to design a framework for course planning specifically for incorporating sustainability into the existing engineering curricula, the study has modified the constructive alignment model and adapted the general concept of sustainability incorporation. As a result, Figure 7.58 depicts the strategies to incorporate sustainability in a `constructive alignment model´ based curriculum.

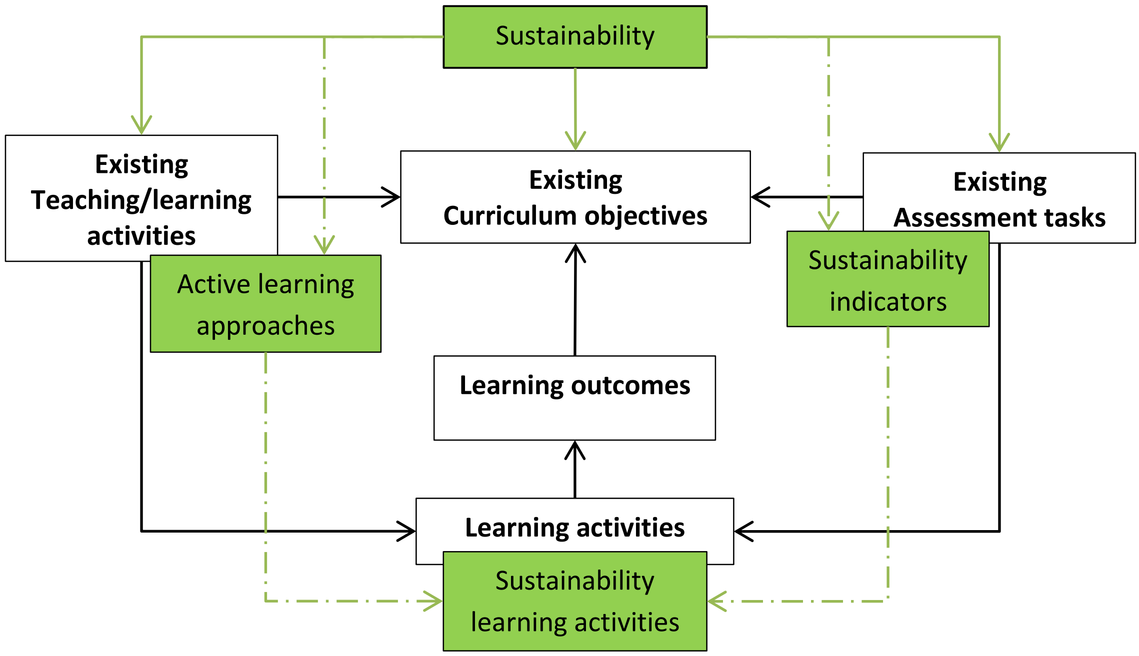


Figure 7.58 Incorporation strategies for a constructive alignment model

This study proposes several changes in the existing curriculum model as presented in Figure 7.58. The incorporation of sustainability has to begin from the existing curriculum objectives, and later the incorporations are made to other elements e.g. the existing teaching/learning activities and the existing assessment tasks, by referring to the new curriculum objectives. This study also proposes active learning approaches as part of the teaching/learning activities, sustainability learning activities integrated into the existing learning activities, and sustainability indicators employed as one of assessment tasks (please refer to Appendix A – A framework to incorporate sustainability in engineering curricula, for further explanation).

Chapter 8

Phase four: Validating design framework

8.1 Introduction

This chapter presents the phase four of the research method which is the process of validating design framework and collecting feedbacks from teachers. The phase started with introducing the intervention. In this phase, the intervention is the introduction of a framework to incorporate sustainability into the existing engineering courses. This chapter also presents the process taken in conducting the intervention (the workshop) which includes invitation of participants procedures, process of structuring the workshop and the process of collecting feedback from the participants (the activities in the workshop). Data were collected qualitatively by implying several data collection techniques such as document analysis, open-ended questions and informal interviews. In overall, the validating process can be depicted in the following figure.

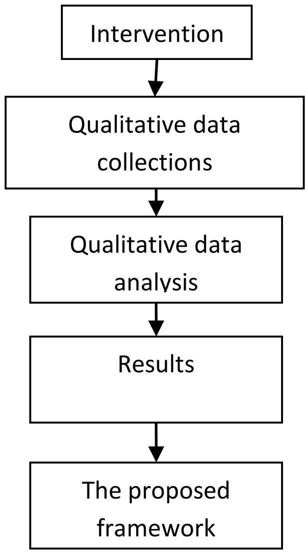


Figure 8.1 Pre-experimental design

8.2 Intervention

On the 8th and 9th of July 2013, a two-day workshop was conducted in order to commence the phase four of this research study. A total of 12 engineering and technical teachers were invited to participate in the workshop. The workshop called *Integrating Sustainability in Engineering Curricula Workshop* has only managed to attract four teachers. Two of them were engineering teachers and the remaining two were technical teachers.

Inviting teachers - The Sampling method

The samples were selected based on two main criteria. First, the sample has participated in the previous phase two and phase three research processes. Second, the sample is familiar with course design and sustainability. The criteria were set to meet the requirements of the target group of the design framework. As a result, twelve engineering and technical teachers were invited.

The preparation of this workshop i.e. documenting the design framework, inviting prospective participants, had been started three months earlier. The workshop dates were set according to prospective participants´ preference. Informal invitations were sent via email to all prospective participants, asking their availability and preferences on the proposed dates and venue. Later, the formal invitation letters were sent to the prospective participants.

Structuring the workshop – pre work before intervention

As the intervention was planned in the form of workshop, there were several issues raised in structuring the program. Issues such as how the framework will be presented, the suitable data collection technique, participants´ expectations, multidisciplinary of participants´ background and the variety of understanding on Sustainability were taken into consideration. The following figure shows how the issues influence the process of structuring the workshop.

The main objectives of workshop were determined based on the research aims stated in the phase four research method. The workshop objectives were also determined by concerning the prospective participants´ expectations and background. Later, the workshop objectives were used as points of departures for designing the workshop contents, programs and assessments.

Figure 8.2 shows that the requirements of the framework influence the contents of the workshop and the selection of prospective participants. The participants are expected to have experience in designing course and working in sustainability area or have at least the basic knowledge of sustainability. Therefore, in the process of selecting contents of the workshop, there was no or little discussion on the topic of course design and the concepts and principles of sustainability. Yet, the expectations of the prospective participants have been considered.

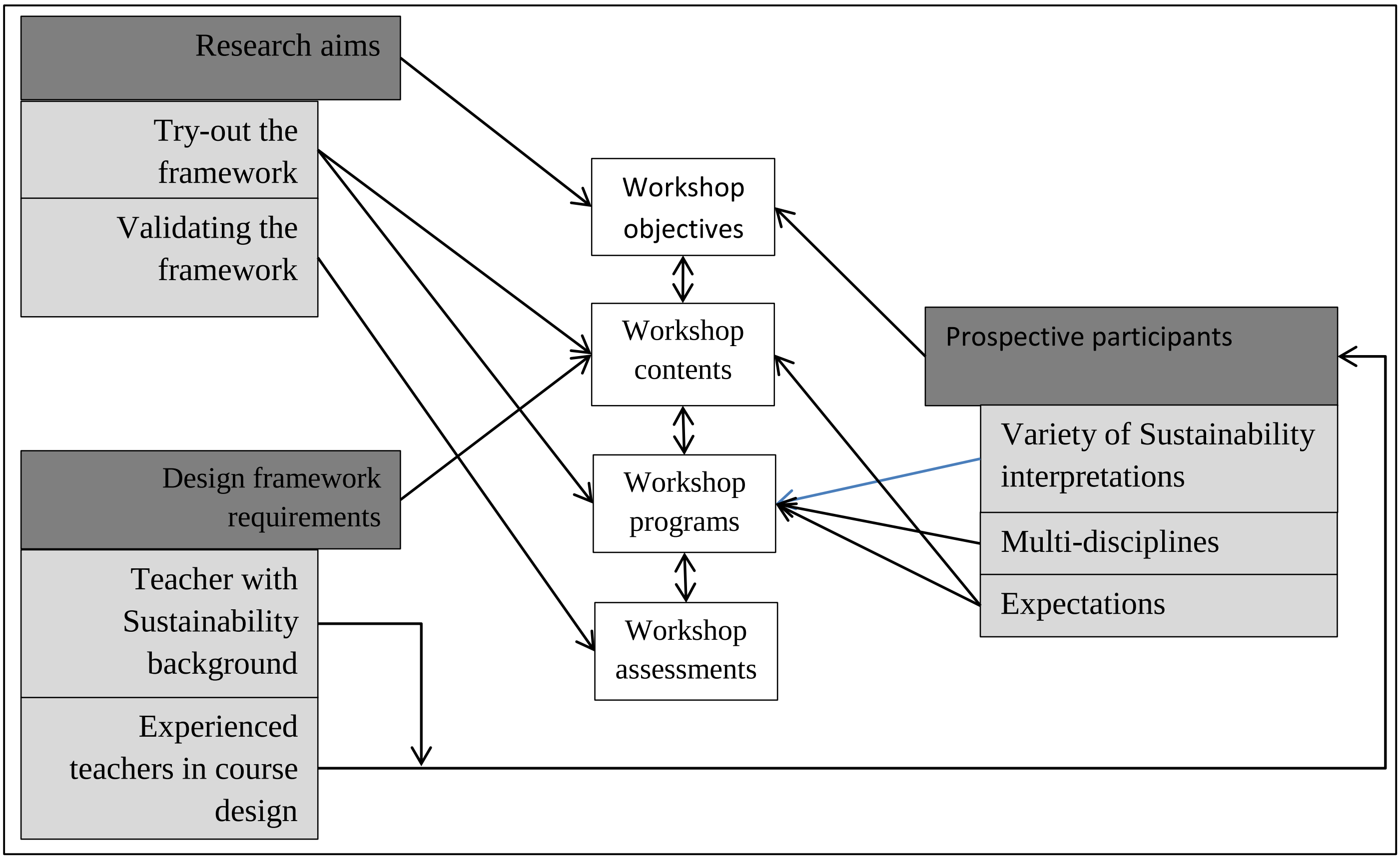


Figure 8.2 Structuring the workshop

The contents of workshop are mainly focused on delivering the documented contents of the framework i.e. models, approaches and concepts, and strategies to integrate sustainability. The workshop also includes discussions on the basic concepts and principles of sustainability to comprehend the teachers' understanding as well as finding their mutual understanding on the topic. For delivering the contents, two sets of presentations slides, hardcopies of design framework and reference books were provided.

The workshop was set on the second semester break, where it was not examination weeks or lecture weeks. It was also set for two days and 2 hours in duration. On the first day of workshop, the program was structured to allocate almost two hours for participants to discuss the fundamental concepts of sustainability. On the second day, the participants were asked to read through the document (the framework) and later the participants gave feedbacks based on their experiences in the field of sustainability and designing course.

The assessment part of the workshop was used to gathering feedbacks from participants. The feedbacks were collected as aligned with the objective of the workshop which is to validate the design framework. The data were gathered qualitatively, in which it offers more insights from the participants. With a small size of respondents, quantitative data collection techniques might be insufficient and the results might be questionable for validity.

Outlining the workshop – Program outlines

For the purpose of documentation, the program is outlined into several categories. The categories are name, duration, target group, objectives, contents, programs and assessments. The outlines have been distributed to the participants and used as formal schedule for researcher and participants throughout the workshop.

Table 8.1 Outlines for Integrating Sustainability in Engineering Curricula Workshop

<table>
<tr><td>Name</td><td colspan="2">Integrating Sustainability in Engineering Education</td></tr>
<tr><td>Duration</td><td colspan="2">4 hours</td></tr>
<tr><td>Target group</td><td colspan="2">Engineering and Technical Teachers in UTM</td></tr>
<tr><td>Objectives</td><td colspan="2">At the end of this workshop, participants are able to:
1. Apply the design framework to integrate sustainability in engineering curricula
2. Give feedbacks on the framework in terms of deliverability and practicality</td></tr>
<tr><td>Contents</td><td colspan="2">6. Concepts and Principles of Sustainability
7. Framework to integrate sustainability in Engineering Education</td></tr>
<tr><td rowspan="11">Programs</td><td colspan="2">8th July 2013</td></tr>
<tr><td>10:00 am</td><td>Welcoming and Greeting the participants
Briefing on the purposes of the empirical studies and research objectives</td></tr>
<tr><td>10:15 am</td><td>Activity 1: Sustainability in Engineering Education – Sharing our perspectives</td></tr>
<tr><td>11:15 am</td><td>Activity 2: Sustainability in Engineering Education – Finding our mutual understanding</td></tr>
<tr><td>12:15 pm</td><td>Lunch</td></tr>
<tr><td colspan="2">9th July 2013</td></tr>
<tr><td>10:00 am</td><td>Briefing on a Framework to Integrate Sustainability in Engineering Curricula</td></tr>
<tr><td>10:30 am</td><td>Activity 1: Testing the framework</td></tr>
<tr><td>11:30 am</td><td>Activity 2: Reflecting on the effectiveness</td></tr>
<tr><td>12:00</td><td>Lunch</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Assessment</td><td colspan="2">There were two key questions posted in order to measure the framework. The key questions were deliverability and practicality of the framework.</td></tr>
</table>

Executing the workshop – Day 1

The motivation of executing the first day of the workshop began low. The workshop only started after almost thirty minutes of waiting for all the participants to arrive. As introduction, the workshop began with a brief explanation on the PhD project that has been conducted for two years and a half. The introduction part also includes presentation on the purposes of empirical study, the research objectives and the research design. Figure 8.3 shows the captions of slides presentation for the first day of the workshop.

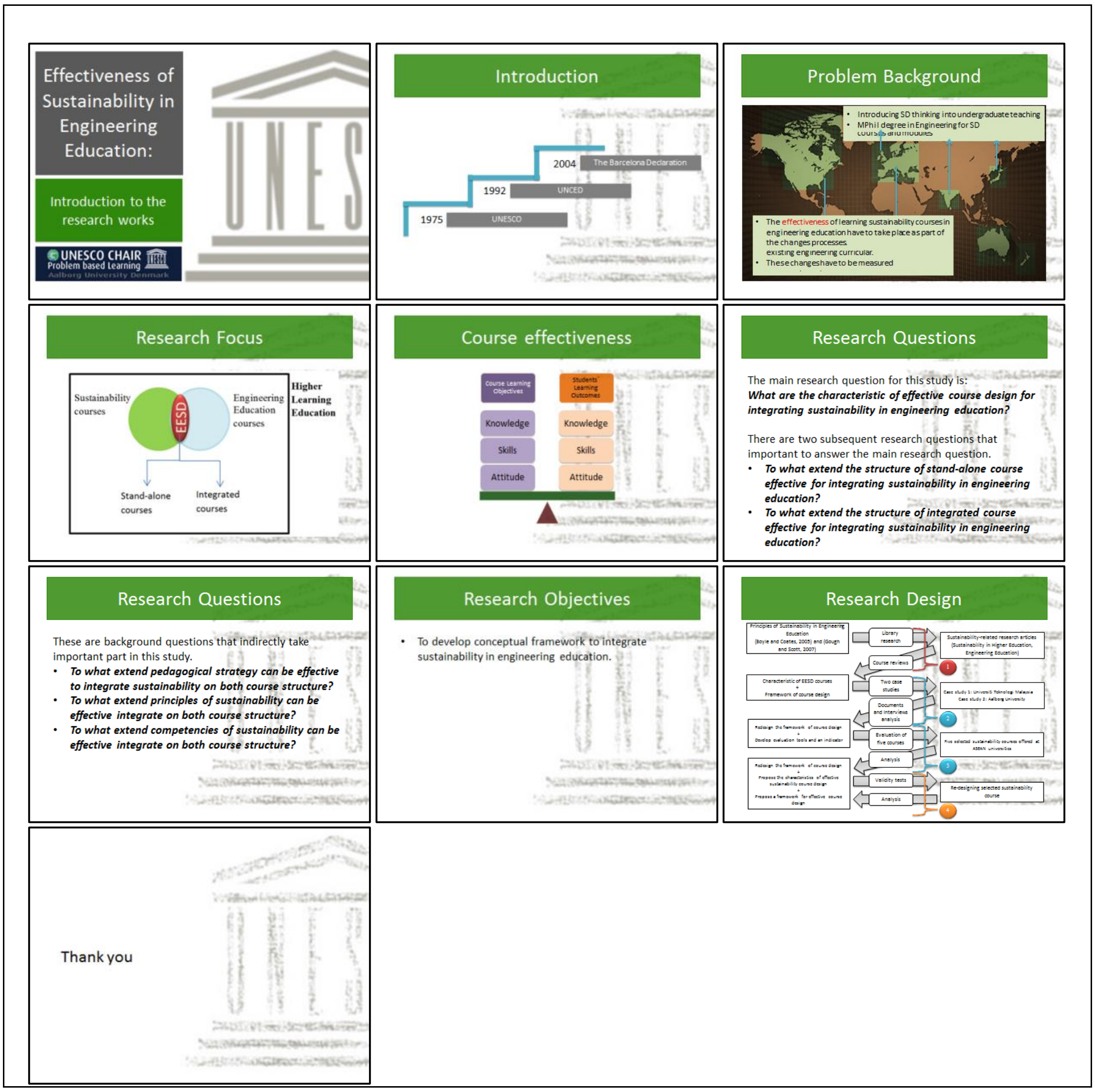


Figure 8.3 Slides presentation for Day 1

Before the participants proceed to the first activity, they were provided with a presentation of Conceptual Maps. The explanation had unexpectedly taken a longer time because some of the teachers were not familiar with the Conceptual Maps. The caption of the presentation is depicted in the following Figure 8.4.

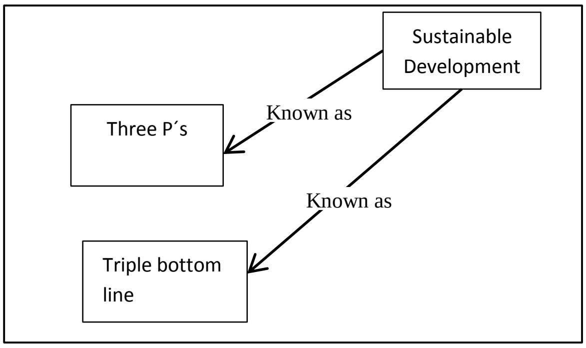
Conceptual Maps

Conceptual maps are graphical tools for organizing and representing knowledge. The main features of the concept maps are:

i) Concepts, which usually enclosed in circles or boxes.
ii) Connecting line, which linking between two concepts
iii) Words on the line, which referred to as linking words

For example,

A concept map always starts with a general concept, for this case *Sustainable Development* is the general concept. It is in the top of the hierarchy of the concept. The more specific concepts are arranged in lower hierarchy, for this case are *Three P´s* and *Triple bottom line*. Both concepts are connected with arrows and *known as* is the linking word.



Below is an example of the concept maps for Sustainable Development.

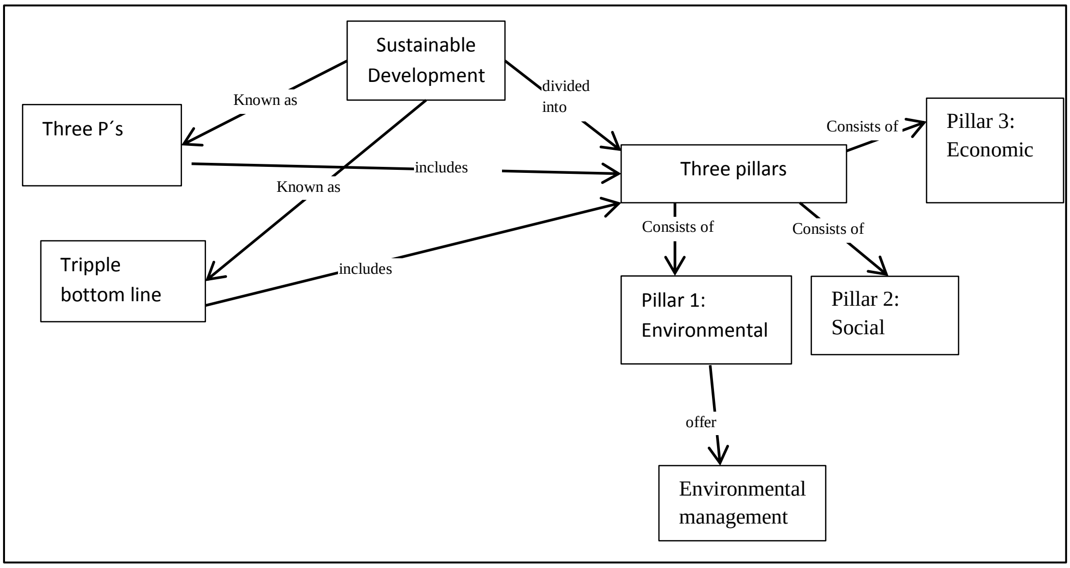


Figure 8.4 Presentation for explaining Conceptual Maps

Activity 1: Sustainability in Engineering Education – Sharing our perspectives

After the first forty minutes had ended, the participants were asked to form a group and take some time for *ice breaking* activity (to know each other). In their group, the participants were working together and sharing their understanding on the concepts of sustainability. At the beginning of the group work, the discussions have been directed by a senior teacher. The team members basically were only giving their opinions after they were asked for. As the time passed, the group discussion were more dynamic, each of team members expressed their opinions independently and make arguments.

Figure 8.4 A group discussion

In the group, participants discussed their perspectives on Sustainability in Engineering Education by sharing their understanding on sub-concepts of sustainability. Each of them jotted down the sub-concept(s) of sustainability first on a piece of paper, before they pasted it on the white paper and start expressing and explaining the sub-concept(s). At the end of activity 1, the group had collections of sub-concepts of sustainability in Engineering Education.

Activity 2: Sustainability in Engineering Education – Finding our mutual understanding

In activity 2, the participants were asked to use their collections of sub-concepts of sustainability in Engineering Education and develop conceptual maps. In this activity, the participants worked together to connect every sub-concept to the main concept which is Sustainability in Engineering Education. Along the activity, by observation, the participants developed their mutual understanding on the main concept and reflecting their understanding to the others´.

The following Figure 8.5 depicts the final outcome of the group discussion. The presented Conceptual Maps however have missing connection words such as *includes, known as* and so on. After they completed the task, one of the team members presented the concepts of Sustainability in Engineering Education based on the Conceptual Maps.

Before the workshop ended, the participants also had opportunities to give reflections based on the Introduction part of the workshop, Activity 1 and Activity 2. All of them were satisfied and admitted that these activities have helped them to understand better the concepts and principles of sustainability especially in the context of engineering education.

Figure 8.5 A caption of the final outcome of group discussion

Executing the workshop – Day 2

In day 2, the workshop began with the introduction of the framework. Each of the participants was provided with a file that contains 36 pages of strategies to integrate sustainability in engineering curricula. It is a composite of strategies in governing sustainability competencies, contextualizing sustainability, structuring course and integrating sustainability in course planning. The presentations were given by the facilitator of the workshop (the researcher) for almost an hour and followed by explanation of the document.

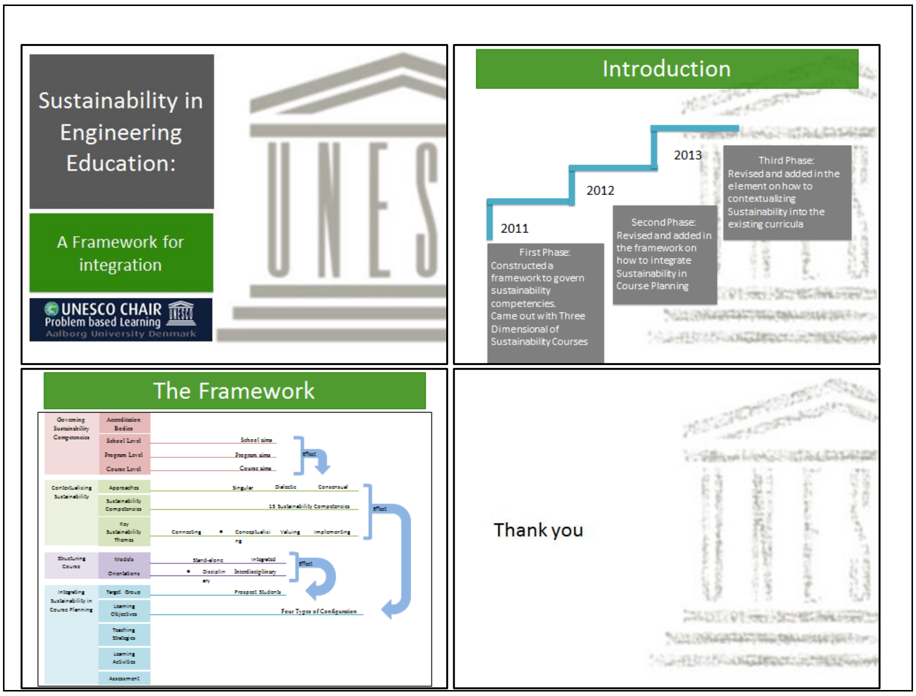


Figure 8.6 Slides presentations for Day 2

Activity 1: Testing the framework

Individually, participants had tried out the framework. Participants used their own engineering course/program as a sample and employed the framework to integrate sustainability. In this activity the participants also made some comments on the framework for every part that is problematic and needs more explanation.

Activity 2: Validating the design framework

In activity 2, all participants have been asked to give reflections based on two aspects. First, they reflected the framework in terms of its deliverability including the capability of the framework to present the ideas and models, and the capability of the framework to provide understanding of the ideas and models to the users. Second, the framework also has been validated in terms of it practicality aspect including the aspect which focuses on the capability of the framework to engage teachers with the overall design process and the capability of the framework to apply to the existing engineering courses.

The activity was performed in a group. The participants gave feedbacks in systematic way where the discussion began on the overall framework and to the next following the design process. The participants also employed conceptual maps to illustrate their opinions. They also put some notes or comments on the given document, therefore the researcher could have a better understanding. Figure 8.7 shows the slides used for the activities.

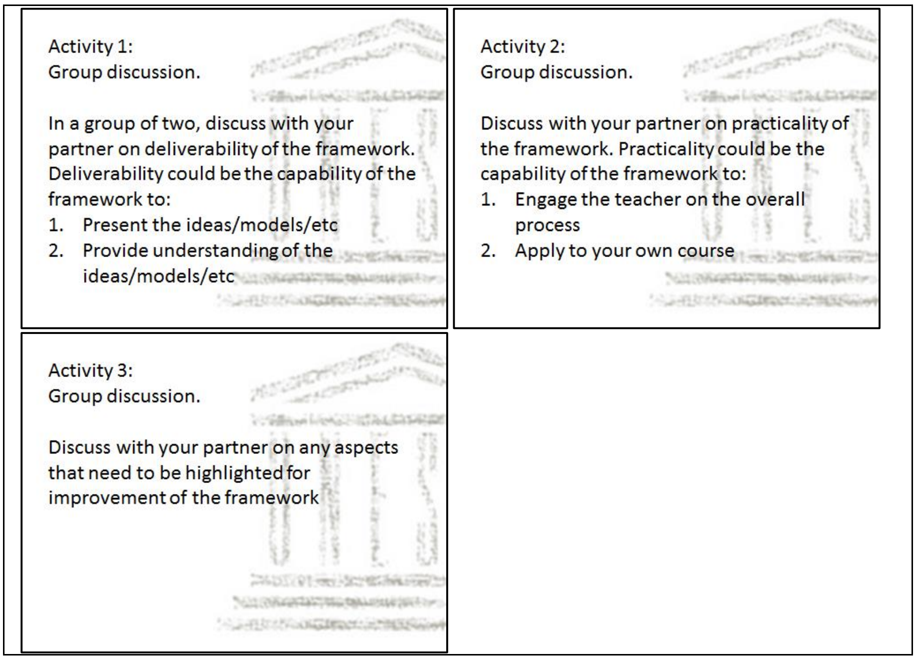


Figure 8.7 Caption of slides presentation for activity 2

8.3 Results and discussions

Both outcomes from the first and the second days of workshop were presented in Conceptual Maps. However the Conceptual Maps from the first day were used as a tool for participants to understand better the concepts and principles of sustainability in engineering education. The data were also purposely used for the participants in sharing their perspectives and finding mutual understanding on the concepts and principles of sustainability in engineering education. The data from the second day on the other hand were collected to validate the design framework.

Based on the Conceptual Maps from the second day, the data had been analyzed according to two aspects of its deliverability and practicality. The results of the analyses will be presented in the following discussion.

Deliverability aspect of the framework

A. *Capability of the framework to present the ideas*

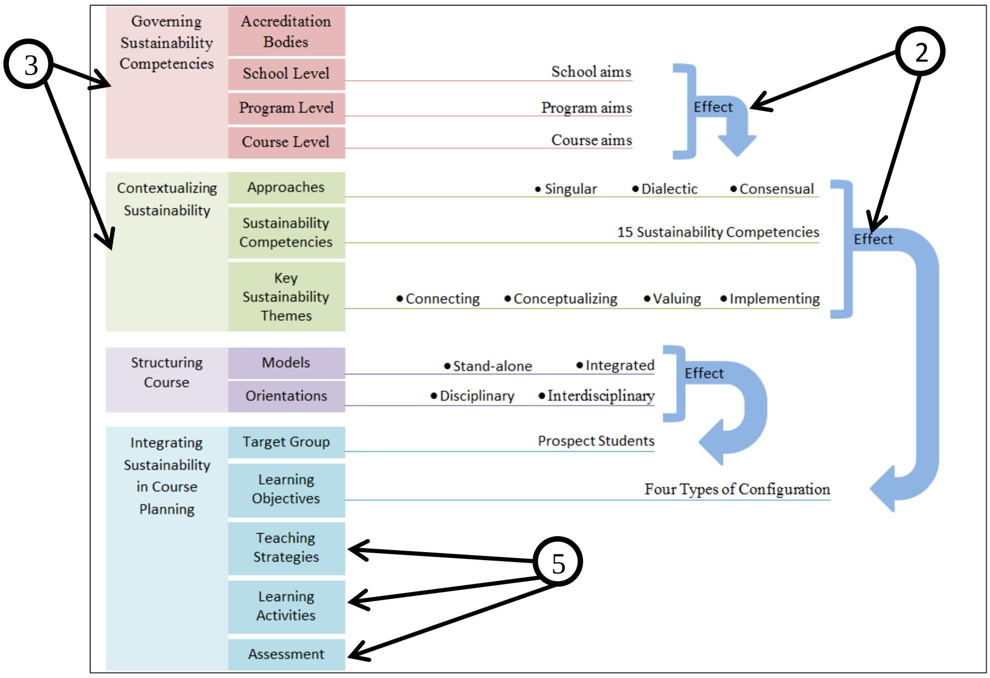


Figure 8.8 Comments on the overall framework

1. The overall framework depicted the whole process of integrating sustainability in engineering curricula.
2. Effect arrows need a little explanation. The arrows from the figure itself might be interpreted as a transition from one phase to the next or expressed to the readers as cause-effect paradigm.
3. Even though the boxes are positioned in top-bottom coordination, it might be interpreted either as a procedure or a separate process. Therefore it is recommended to use transitional words such as Phase 1, Phase 2 and so on.

4. Other than using transitional words, it is also possible to use color (from dark to light color) to express that the activities are in sequence.
5. Some of the elements depicted in the overall framework look incomplete. Should consider putting key words.
6. If the elements are not supposed to be interpreted as sequential activity, rearranging the diagrams should be considered.

B. Capability of the framework to provide understanding of the ideas

1. The use of "School" as a part of the processes to govern sustainability competencies will make some other teachers from other universities puzzled. School is commonly called as Faculty in most universities in Malaysia. School usually refers to an institution for lower education.
2. Other than School level, teacher should also have to take into account the sustainability competencies in University and Department levels.
3. Listing down fifteen sustainability competencies is rather prescriptive. It is recommended to sustain the flexibility of the framework. Other elements of sustainability that could possibly be uncovered with the listed fifteen elements.
4. A framework that contains sequential activities or procedures such as the proposed framework of sustainability integration. It is recommended to add feedback or feed forward mechanism, therefore the framework has check-in-balanced or improvement element.

Practicality aspect of the framework

A. Capability of framework to engage teachers in design process

1. The framework and the supporting descriptions should be documented together with the basic concepts of sustainability and Course design. Both topics should briefly be written and it should aim to refresh the understanding of teachers or course developers.
2. It is recommended to include who are the target groups and what is the pre-requisite knowledge for using the framework in the introduction part.
3. The framework by itself could not help teachers to incorporate sustainability if the process does not include the readiness aspect of the teachers.
4. The framework also demands institutional supports especially for staff development. The framework proposed Student-centred Learning as teaching strategies and several learning activities that might not be familiar to teachers. Therefore, educational training for staff development such as curriculum design and pedagogy are needed.

B. Capability of framework to apply to the existing courses

1. The framework will only function if the pre-requisite knowledge and institutional supports are fulfilled.

2. Some examples of sustainability courses could give aspirations to the teachers to integrate sustainability into their own course.
3. To make a stand-alone framework (do not need any assistive documents or face-to-face training), some of the elements in course planning need more explanations and details such as procedures taken to construct course learning objectives which consider levels of knowledge, skills and attitudes.

8.4 Conclusion – Finalizing the proposed framework design

In overall, the two-day workshop was successful in providing a platform and opportunity for researcher to conduct the final phase of research design. The knowledge and experience sharing session in the first day was a good practice to gain understanding and find a mutual understanding of the concept of sustainability amongst the respondents. This session was also important for the research because it reduced the effects of the variety of respondent's sustainability knowledge. Therefore,the respondents evaluated the framework according to the needs of the research without having huge arguments on the sustainability knowledge.

Introducing the framework as an intervention to the respondent´s practices in incorporating sustainability in the second day of the workshop has produced important results for improvement. The respondents accepted the intervention as a crucial effort to make transformation on the existing engineering curricula towards sustainability. In fact, the intervention might contribute to UTM´s effort to be a Sustainable Campus.

As a result from the process of validation, a complete document and explanations of the proposed framework are presented in Chapter 9. However, the following Figure 8.9 depicts the final illustration of the overview of the framework. The figure includes several changes that have been made by considering respondent´s feedbacks. The changes are:

i. Inserting transitional words (phase I, phase II, phase III and phase IV) in every phase of design process, so that users could easily understand the flow of the design process,
ii. Stating clearly the important remarks or the proposed models in each phase,
iii. Reorganising the feed forward and feedback arrows according to the need for alignment. The arrows also provide a check and balance mechanism,
iv. Replacing the word `effect´ with `align´. This replacement conveys accurate connections between two design phases,
v. Deleting the `target group´ component in phase IV due to irrelevant component for sustainability incorporation,

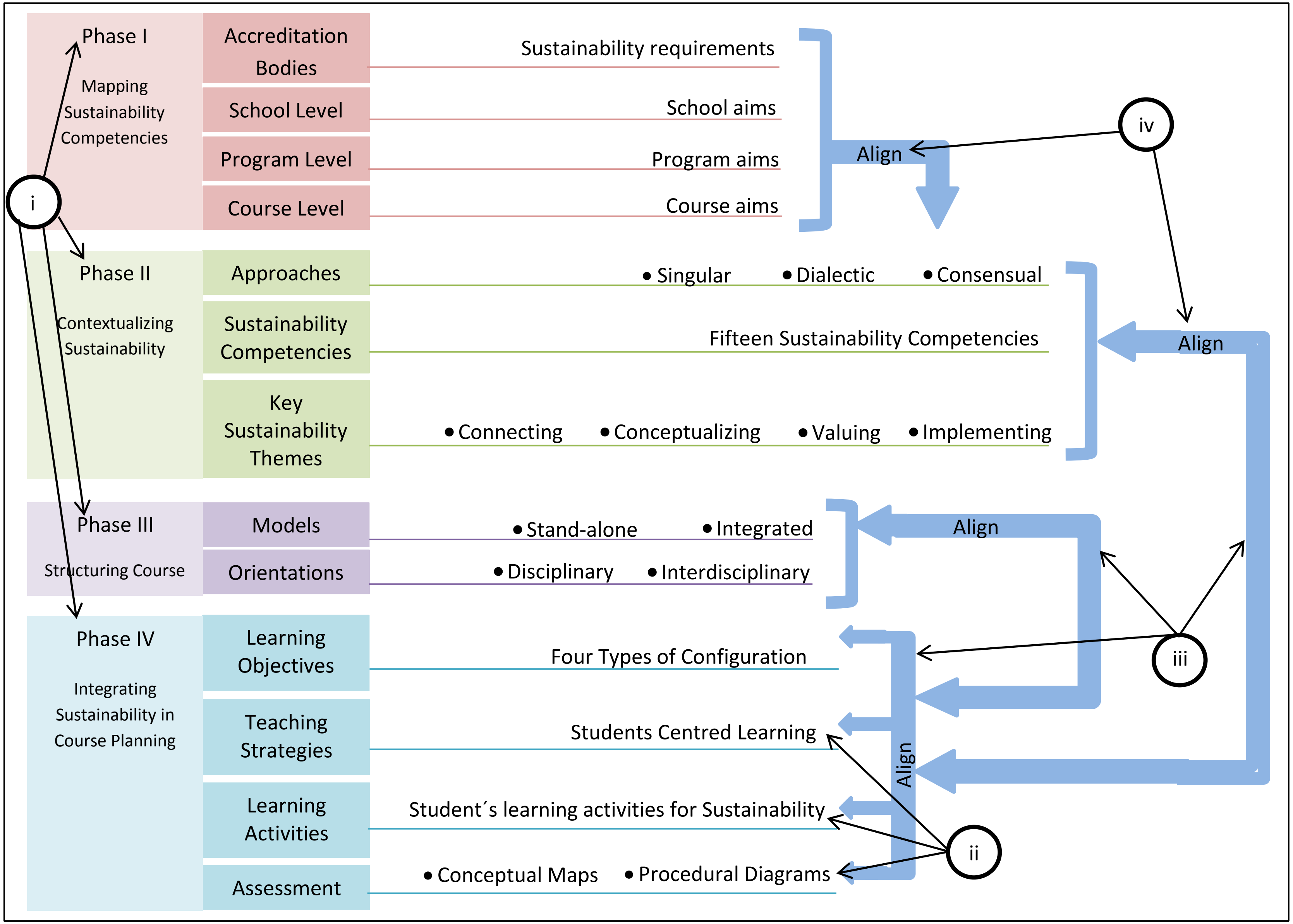


Figure 8.9 Finalizing the overall framework

Chapter 9

Conclusion and recommendations

9.1 Introduction

This is the final chapter that will provide overall conclusion and recommendations. It highlights several findings and proposals that have been made to address each research question and to achieve the research objectives. Therefore, the presentation of this paper is according to the four research questions presented in Chapter 1. Further to the end, the researcher will make reflections on the research process and the proposed framework to incorporate sustainability in engineering curricula. Several recommendations in relation to the efforts of engineering education for sustainable development are also presented in this chapter as a point of departure for future research works.

9.2 What is the current practice of the sustainability incorporation in engineering curricula?

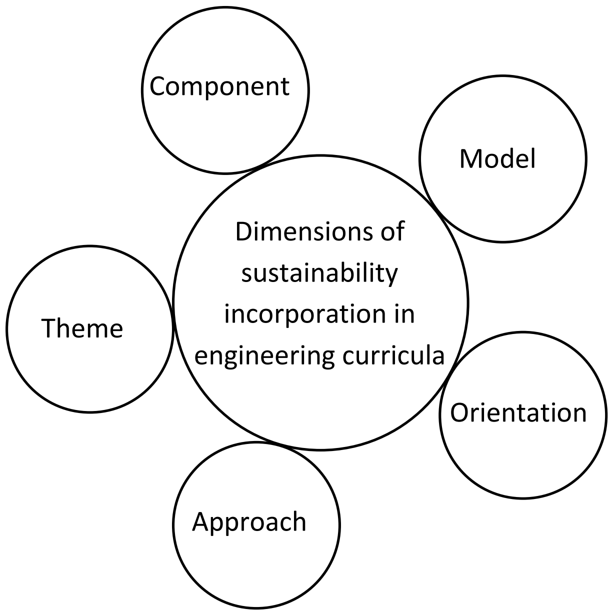


Figure 9.1 Sustainability incorporation in engineering curricula

In research phase 1, this study presented the exploration of several institutions practices in incorporating sustainability in engineering curricula. The exploration involved university works that have been published in proceeding and journal articles, as well as documented in university curricula. As inductive and deductive analytical techniques were applied to analyse the data, the research proposes that there are five main dimensions of sustainability incorporation.

The presented dimensions of sustainability incorporation in engineering curricula can be used as a method to characterize the existing sustainability courses and to provide an overview of the university practices. By characterizing the existing sustainability courses into the dimensions, it can provide some form of reflections on the aspects that are related to course design. Therefore, the teachers or course coordinators could highlight the potentials of the existing engineering courses and later in the future redesign the courses for improvement.

The dimensions consist of model, approach, orientation, theme and component (see Figure 9.1). Model is a dimension to construct a sustainability course; it has been further developed on the basis of six cases (Kitamura and Hoshii, 2006; Salih, 2008; Holmberg, 2008; Coral, 2009; Murphy, 2009 and Chhokar, 2010). The model has been proposed in two types. The first type, a stand-alone model, represents a sustainability course that has been newly developed for engineering students without redesigning the existing engineering course. The second type, an integrated model, characterizes a sustainability course that has been developed by integrating sustainability knowledge into the existing engineering course. Orientation of sustainability course characterizes the area of knowledge that is applied to develop course learning objectives and contents. This research has proposed two types of orientation that are represented in this dimension. Disciplinary orientation represents the focus of sustainability course in providing sustainability knowledge and competencies to fit into a specific discipline. On the other hand, a sustainability course that provides knowledge and competencies from more than one discipline is called an interdisciplinary orientation.

Next dimension for sustainability incorporation is approach. Building on three types of approach, a sustainability course can be characterized either as a singular approach, dialectic approach or a consensual approach. Each approach signifies the focus of knowledge in integrating the three main pillars of sustainability (environmental pillar, social pillar and economic pillar). For a sustainability course that focuses only on one of the pillars, it is called as a singular approach. On the other hand, sustainability course that focuses on two of the pillars is called as dialectic approach, and a consensual approach for sustainability course equally balances all the three pillars.

The next dimension that is proposed in this research is theme. The key themes of sustainability consist of i) connecting sustainability to the engineering professions, ii) conceptualizing sustainability into engineering designs, iii) valuing sustainability in engineering justifications and iv) implementing sustainability into engineering solutions. These themes represent a method to incorporate the knowledge of sustainability into engineering professions and practices. It relates to the selection of the knowledge of sustainability that is complex and covers a wide area of disciplines. For instance, the first theme characterizes sustainability course that incorporates sustainability knowledge that is more non-technical and abstract. The purpose of employing this theme is to connect engineering as a profession with the fundamental concept of sustainability.

Component of sustainability is the last dimension for the incorporation. It represents the knowledge or area of topic that relates the concept of sustainability and the requirement to achieve sustainability. The components emerged from the analysis of the sustainability concepts and sustainability courses for engineering education, and it can be categorized into sixteen major components. The components are i) fundamental concepts of sustainability, ii) empowerment of engineer, iii) environmental management, iv) environmental assessments, v) preservation of resources, vi) social rights and social values, vii) concern on citizenry issues, viii) equity of inter-generation and intra-generation, ix) preserve culture, x) quality in engineering, xi) green or eco technology, xii) holistic approach/integrative approach, xiii) stakeholders, xiv) concern on global issues, xv) concern on local issues and xvi) development of economy. These components are also commonly incorporated in current engineering education.

Other than identifying the current practices on structuring sustainability courses in engineering curricula, this study had also conducted a series of interviews amongst experts of sustainability around the globe to understand further on the profile for each component. For that reason, the researcher had reduced the number of components so that the experts could rank them according to the priority in current practices and explain further the importance of each component for engineering education. Table 9.1 depicts the result that emerged from the analysis. It is clearly shown that the most important component for sustainability in engineering education is the fundamental knowledge concept of sustainability. This is followed with engineering solutions considering the resources and ecosystem, engineering solutions for global problems, and so on. The table also depicts that the components such as engineering solution in terms of quality and engineering solutions based on economic aspect are least important.

The ranking list demonstrates to what extend the equilibrium idea of sustainability is implemented or perceived important amongst universities. The idea of equilibrium in the concept of sustainability is by valuing equally the environmental, social and economic dimensions (Pearce, 1988; Harding, 2006; Voinov and Farley, 2007; Lozano, 2008; and Moldan, Janoušková, and Hák, 2012). Under-representing one of the dimensions will lead to unsustainable world. Therefore, it is important to balance these three dimensions in engineering education.

Based on their experiences and believes, most of the respondents believed that environmental dimension is highly important for engineering education with regard to sustainability. They also believed that this dimension has been under-represented in most of the engineering practices. This belief has led to higher number of sustainability courses focusing on environmental aspect in engineering education (see Table 5.5, Chapter 5). It is also important to remark the under-represented social aspect in engineering education. Several results in this study show that there is a lack of focus on social dimension amongst sustainability experts in engineering education and sustainability discourses related to engineering education. Therefore, it is highly important for course coordinators or course developers to check-and-balance the current engineering curricula, and make a transformation to the curricula for improvement.

Table 9.1 Current focus on sustainability in engineering education

Rank	Components of sustainability	Environmental	Social	Economic
1	The fundamental concept of sustainability	●	●	●
2	Engineering solutions considering the resources and ecosystem	●		
3	Engineering solutions for global problems	●	●	●
4	The knowledge of environmental management	●		
5	The knowledge of environmental assessments	●		
6	Engineering solutions based on criteria set by stakeholders		●	●
7	The engineering ethics	●	●	
8	Engineering solutions for local problems	●	●	●
9	Engineering solutions in terms of quality			●
10	Engineering solutions based on economic aspect			●

9.3 What are the considerations taken by the studied universities to incorporate sustainability in engineering curricula?

This research particularly addressed the second research question through research phase 2, highlighting positive practices. Several case studies were carried out at Universiti Teknologi Malaysia (UTM) and Aalborg Universitet Denmark (AAU). Both universities were selected as the researcher has fully capacity to access internal documents and get insights from peers (teachers and course coordinators). Involving teachers and course coordinators in this research was a huge task especially dealing with respondents´ time schedules and participations. However, this research phase has been successfully conducted by participation of teachers and students from ten courses across engineering fields and produced research outcomes that highly contribute to design a framework.

From the outcomes, there are three main factors that have to be put in consideration for teachers and course coordinators to incorporate sustainability into the existing engineering curricula. First, courses that are offered in both universities have to fulfil the requirements set by the internal or international accreditation/evaluation bodies. In the case studies in UTM, each of the courses has to be aligned with criteria proposed by Engineering Accreditation Council (EAC). The body has introduced eleven generic attributes for engineering graduates in Malaysia (Aziz *et al.*, 2005). For instance, the body has outlined that the programs offered must produce students that are *"well respected and potential industry leader, which provide engineers which are able to understand the impact of engineering solutions in a global/social context, knowledgeable of contemporary issues, able to communicate effectively and be involved in community or social projects"*. In the case studies in AAU, the Danish Qualification framework has steered the development of curricula by describing the desired outcomes and competencies. One of the components that have been highlighted is the consideration of the aspect of environmental management and corporate social responsibility in business. Both accreditation body and qualification framework have contributed to the incorporation of sustainability in engineering curricula at UTM and AAU; however the criteria are the top priority to be fulfilled.

As one of the Malaysian Higher Institutions, UTM has an obligation to employ Outcome-based Education (OBE) throughout the curricula. OBE has formed curriculum design practices in UTM to focus on student learning outcomes. Together with OBE, UTM has employed a Constructive Alignment Model by Biggs (2009) as the main curriculum model. On the other hand, AAU has a long history of employing problem based and project organized learning as the main pedagogy. The pedagogy applies the principles of learning by doing and experimental learning (de Graff and Kolmos, 2007). The difference in the employed curriculum model in both universities suggests the importance of understanding the models and the potentials to incorporate sustainability. For instance in the case of UTM, the research suggests that there are four potential components in the Constructive Alignment Model that can be used as a platform for the incorporation. The components are curriculum objectives, teaching activities, learning activities and assessment tasks. Therefore, the incorporation of sustainability by taking consideration the employed curriculum model makes the efforts applicable for the teachers and acceptable for the universities. This argument makes the second factor that needs to be considered.

In regards to the components of curriculum design, this brings the discussion to the third factor. The research has proposed a general concept of sustainability incorporation. The concept highlights five components which are learning objectives, teaching and learning approaches, learning activities, learning materials and assessment methods that have potential for the incorporation. Every change made in each component has to be aligned with other components. Therefore the overall design is well structured and contributes to the student learning outcomes.

9.4 What is the effectiveness of the cases in terms of knowledge, skills and attitudes?

In research phase 3, the study had evaluated three cases in terms of its effectiveness. The evaluation processes were conducted on selected engineering courses by gathering teachers' and students' responses. There were three types of instrument specifically designed to evaluate teacher´s expectations and students learning outcomes in terms of knowledge, skills and attitudes. It was built on fifteen components of sustainability in engineering education presented in Table 9.2.

A. *Conceptual maps as an instrument to measure sustainability knowledge*
   Conceptual maps are tools that use graphics to represent knowledge (Novak and Cañas, 2008). The main features of conceptual maps consist of concepts that are enclosed with circles or boxes, connecting lines and connecting words that link two concepts. In this

research, the respondents have been provided with a `how to construct conceptual maps´ procedure and fifteen components of sustainability to be used as the key concept to construct conceptual maps. The fifteen components were taken from one of the research outcomes explained in the first research question. Both sets of the instruments (a set for the teacher and a set for each student) were constructed for the respondents to develop a conceptual map regarding to the topic of sustainability.

B. *Procedural diagrams as an instrument to measure sustainability skills*
Similar to conceptual maps, this instrument also employs graphics as a tool for measurement. The graphics in procedural diagrams are representing a set of procedure. The main features of procedural diagrams are skills that are enclosed by boxes, connecting lines and stages of design. By responding to the question posed in the instrument, teachers and students constructed their own version of diagrams based on their understanding on what are the skills needed to design a *sustainable* engineering solution. Taking a design process that consists of analysis, design, develop and evaluate/testing stages, the respondents constructed a procedural diagram from several non-technical and technical skills, and later self-assessed on each skill by employing a five-point score.

C. *Self-administered questionnaire as an instrument to measure sustainability attitudes*
Two versions of self-administered questionnaire (teacher version and student version) were developed to measure attitudes towards sustainability. The teacher version was developed to measure the expectation of the teacher towards students´ attitude on sustainability, while the student version measures the student´s attitude towards sustainability. Both versions were built on 15 components of sustainability in engineering education, and constructed with 32 close-ended questions. By indicating the respondents' feedbacks in a Likert scale, the questions were constructed so that the respondents (students) visualise themselves as future engineers and reflect their current attitudes.

Table 9.2 List of component codes

Code	Component	Code	Component
C1	Environmental Management	C9	Citizenry
C2	Environmental Assessment	C10	Culture
C3	Resources	C11	Stakeholders
C4	Green/Eco Technology	C12	Empowerment of Engineer
C5	Economic	C13	Holistic / Systemic Approach
C6	Quality in Engineering	C14	Global Issues
C7	Social Rights/Values	C15	Local Issues
C8	Equity		

Course effectiveness

In this research, course effectiveness is defined as the capability of a course to provide a sufficient requirement to achieve course learning objectives. The capability can be measured by comparing students learning outcomes and course learning objectives in terms of knowledge, skills and attitudes. Based on the analyses that have been carried out in research phase 3, the learning outcomes were indicated through an index value. An index value for knowledge represents average percentage of students connecting the components to the concept of sustainability. On the other hand, an index value for skills represents average level of skills for each student while an index value for attitudes represents average level of agreement for each student.

A. *Case A*

   Case A is an engineering course that is offered to chemical engineering students to provide understanding of engineering disciplines and professions. The knowledge of sustainability has been incorporated to connect the concept to the professions. This case employs several teaching and learning strategies such as problem based learning, industrial visits, a competition and series of lecture session. Through the case, the students participated in peer teaching and communicated to community of practice. Result from course evaluation (see figure 10.2) shows that the students´ knowledge is 14% lower than the teacher´s expectation, has very small percentage of sustainability skills, and 9% higher on index value of the students´ attitudes towards sustainability compared to the expectation.

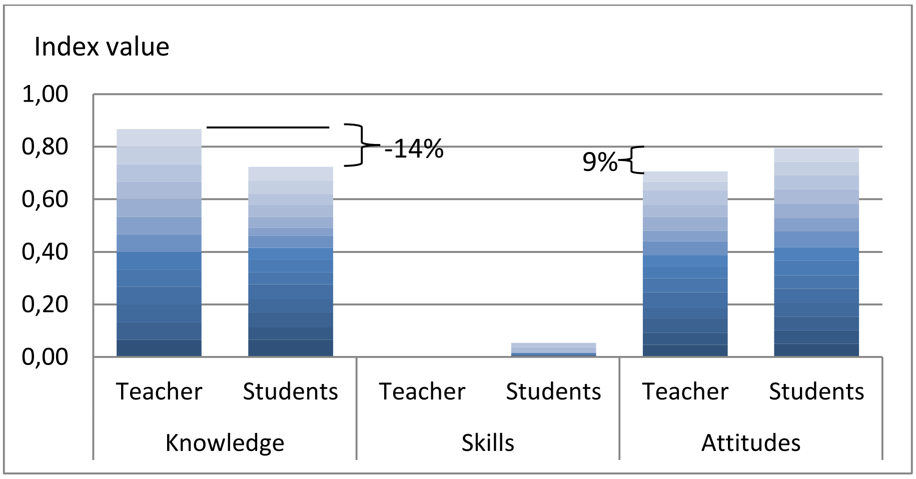


Figure 9.2 Comparison of teacher´s expectation and students learning outcomes: Case A

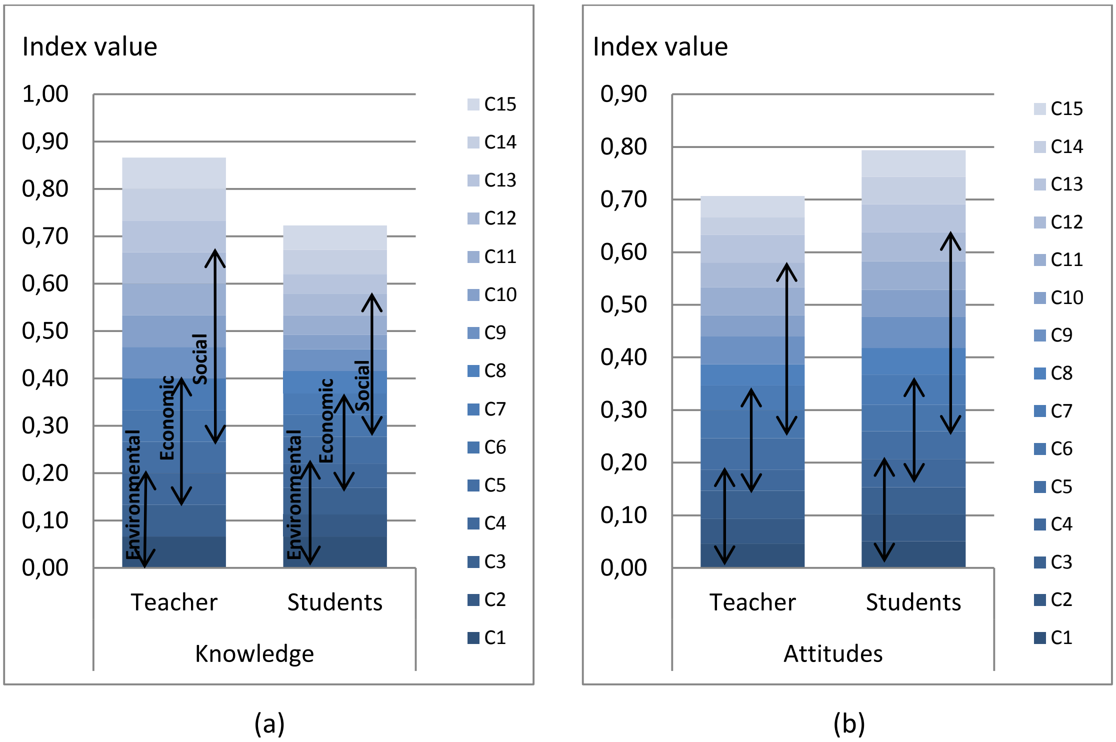


Figure 9.3 Comparison of teacher´s expectation and students learning outcomes for case A, (a) knowledge, (b) attitudes

Figure 9.3(a) depicts that the teacher expected the students to be able to connect engineering as a profession with the aspect of environmental, economic and social. In addition, the teacher also expected the students to relate the profession that involves global and local issues (C14 and C15) and acquire the knowledge of systemic/holistic approach in engineering process (C13). Even though the students' understanding on the knowledge is slightly lower than expected, majority of students were able to connect all components to the concept of sustainability.
In contrast, the index value for students' attitudes is higher than the teacher´s expectation. Figure 9.3(b) shows a strong level of agreement towards the concept of sustainability in engineering professions amongst majority of students on all three aspects especially on the aspect of social. This is due to the higher amount of cumulated index value for social aspect compared to others.

From the analyses, factors that contribute to students learning outcomes are:

- i) Role of teacher – determine the knowledge for learning
- ii) Role of student – contribute in group´s project
- iii) Learning environment – listen to the lecture and participate in group´s project
- iv) Learning materials – case studies
- v) Environment – classroom

According to the factors, it shows that the students have learnt Sustainability from active learning or student centred learning activities such as group project, but in the same time highly dependent on the role of the teacher to determine what they should learn and lectures.

B. Case B

Case B is an engineering course that provides understanding on the role of engineer and the application of sustainability concept in construction for civil engineering students. This case employs several types of active learning and traditional approach as teaching and learning strategies. It includes series of lecture sessions, site visits, community services and research based learning. Along the learning process, students will undergo several activities which are interviewing sustainability experts, communicating to community of practice, preaching the concept of sustainability and participating in research development. Figure 9.4 depicts the result of the comparison between teacher´s expectation and students learning outcomes. It shows that there are 47% of differences in knowledge and 15% of differences in attitudes. In addition, there is a very small difference in index value for skills.

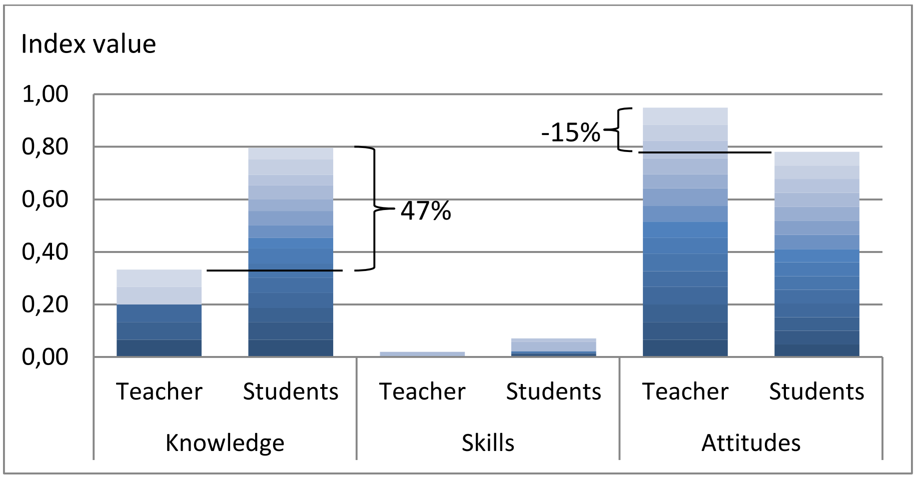
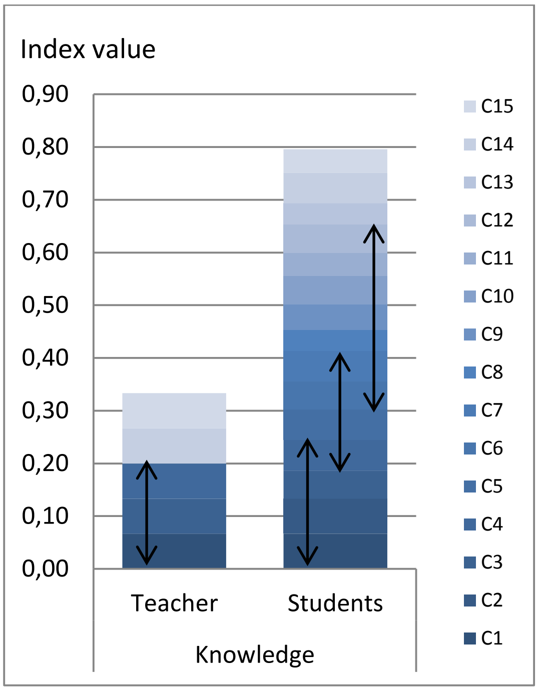
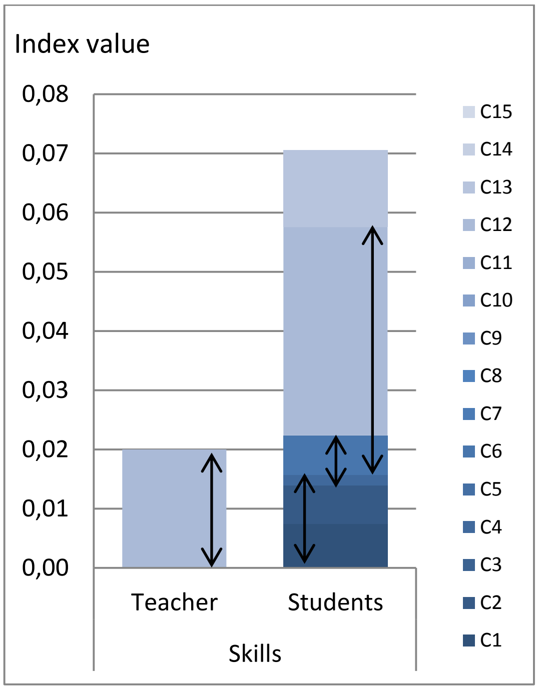


Figure 9.4 Comparison of teacher´s expectation and students learning outcomes: Case B

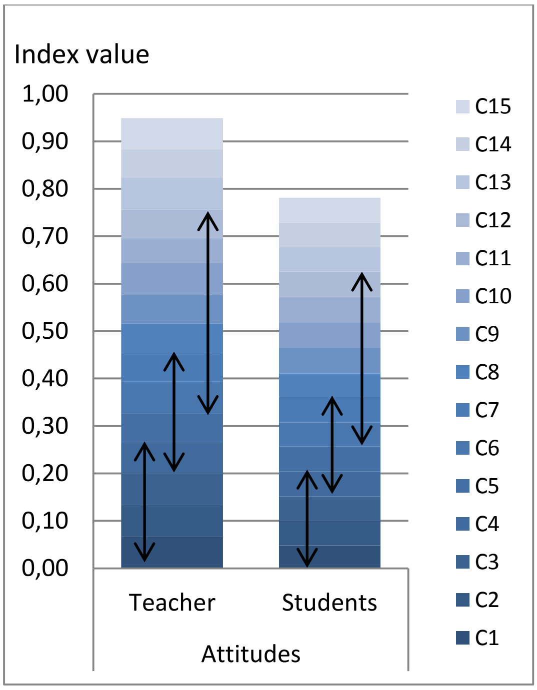
Figure 9.5(a) depicts that the teacher expected that at the end of the course the students are only able to connect environmental aspect to the concept of sustainability. However, the positive result on the comparison between teacher´s expectation and students' knowledge interprets the capability of the course to provide not only knowledge of sustainability that is focused on environmental aspect, but also on social and economic aspects. This is due to the high amount of cumulated index value and the acquired knowledge that is related to all dimensions. In oppose, the result of the analysis depicts that in terms of skills, the course had focused on a single component (C12) of social aspect. From the students´ perspective on the other hand, the result is an evidence of the capability of the course to provide other components of sustainability which include environmental and social aspects. Even though the index values for environmental and economic aspects are relatively very small, it is a positive impact that needs to be highlighted and an input for further improvement and course design.



(a)



(b)



(c)

Figure 9.5 Comparison of teacher´s expectation and students learning outcomes for case B, (a) knowledge, (b) skills, (c) attitudes

From the bar graphs in Figure 9.5(c), the teacher expected that the students have positive attitudes towards all three dimensions of sustainability. Even though the cumulated index value from students´ perspective is slightly lower than the teacher´s expectation, the students had acquired positive attitudes towards the three dimensions. From the probing analyses, factors that contribute to students learning outcomes in this course are:

i) Role of teacher – determine the knowledge for learning
ii) Role of student – participate in group discussion and contribute in group´s project
iii) Learning environment – participate in group´s project and discussion with friends
iv) Learning materials – course materials
v) Environment – classroom

According to the factors, it shows that the students have learnt Sustainability from active learning or student centred learning activities such as group discussion and group project, but in the same time highly dependent on the teacher to determine the knowledge for learning.

C. Case C

Case C is an engineering course that instils some aspect of sustainability such as economic and environmental friendly processes in the principles and methodology of process design. By employing project based learning and traditional teaching strategy, the course provides a learning experience through group project. Figure 9.6 shows the result of the comparison between teacher´s expectation and students learning outcomes. In terms of knowledge, there is no difference in index value, while there are 19% differences on skills and 14% on attitudes.

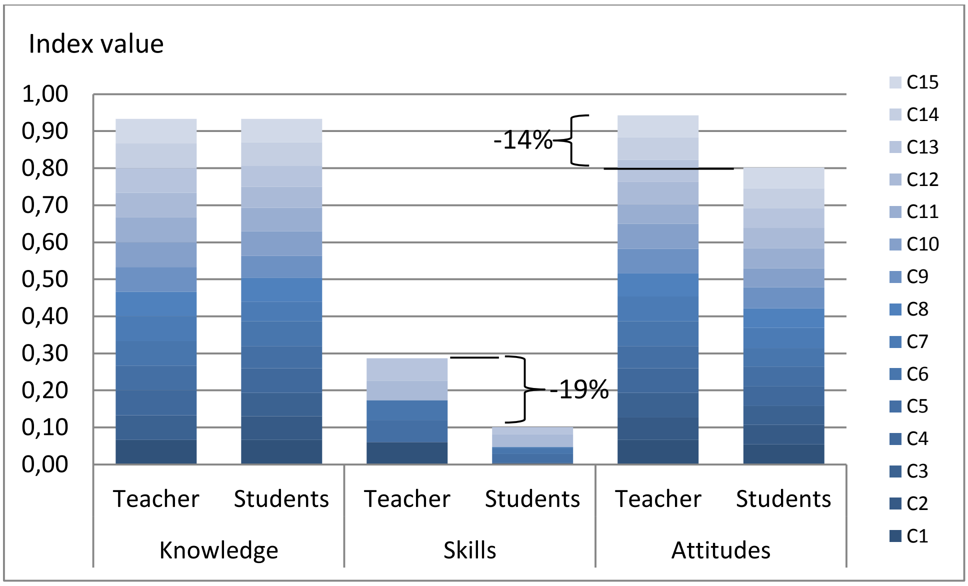


Figure 9.6 Comparison of teacher´s expectation and students learning outcomes: Case C

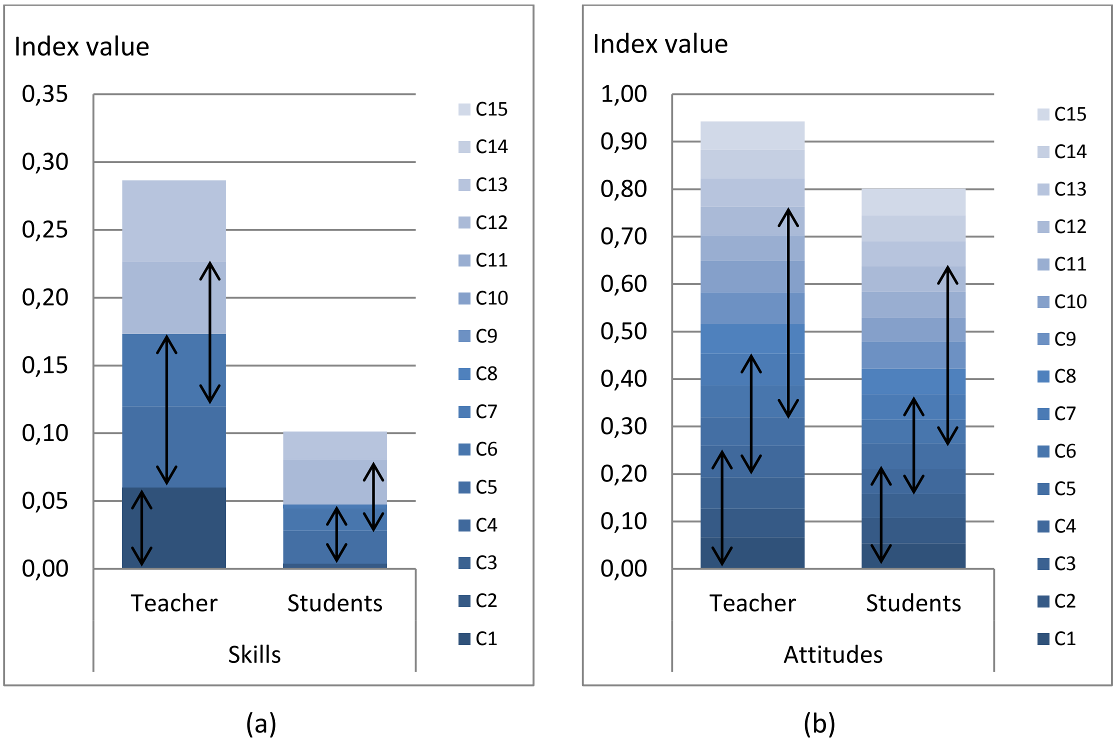


Figure 9.7 Comparison of teacher´s expectation and students learning outcomes for case C, (a) skills, (b) attitudes

The result depicted in Figure 9.7(a) provides an understanding of limited components of sustainability skills that need to be achieved by students. This is due to the small amount of accumulated index value and small amount of components on the bar graph. However, the teacher expected the students to acquire sustainability skills in environmental, economic and social aspects. Based on the measured students´ skills, the accumulated index value is only 0.1 and focused on economic and social aspects. This could explain that the students have lack of skills related to environmental aspect and are unable to achieve to the expected skill level. On the other hand, Figure 9.7(b) depicts the high index values for both teacher and students perspectives. The components of sustainability on both bar graphs also include all three aspects. Due to the small amount of differences between teacher´s expectation and students´ attitudes, this explains that majority of the students had positive attitudes towards majority of the sustainability components in engineering professions.

In addition, the probing analyses highlight several factors that contribute to students learning outcomes. The factors are:

i) Role of teacher – outlined the knowledge for learning with some flexibility
ii) Role of student – participate in group discussion and contribute in group´s project
iii) Learning environment – participate in group´s project, problem solving and group discussion
iv) Learning materials – course materials and case studies
v) Environment – classroom and discussion room

According to the factors, it shows that the students have mostly learnt Sustainability from active learning or student centred learning activities such as group project, group discussion and problem solving activities. The students also have some flexibility in determining what they should learn about Sustainability.

9.5 What are the characteristics of effective sustainability incorporation in engineering curricula presented in both universities?

To characterize the effective sustainability incorporation, the researcher has made reflections from conceptual and practical point of views. Based on the presented literature review (see Chapter 2), the definition of sustainability is viewed important by many scholars to determine and the interpretation towards the concept affects the effectiveness of sustainability incorporation. According to Brundtland (1987), Brown et al. (1987) and Costanza and Patten (1995), sustainability can be viewed as an anthropocentric idea, an idea that accepts the human being as the ultimate value above the others. Hence, the dimension of economic and social are highly valued compared to the dimension of environmental.

In contrast, several studies such as Barlett (1994), Glavič and Lukman (2001), Vos (2007) and Lindsey (2011) viewed sustainability as a concept that highly values environmental aspect than others (an eco-centric view). The studies urged to limit human activities either for economic and social development that endanger to the environment. On the other hand, an equilibrium state between environmental, social and economic dimensions is considered in sustainability for the studies such as Pearce (1988), Harding (2006), Voinov and Farley (2007), Lozano (2008), and Moldan, Janoušková, and Hák (2012). Based on the views, the studies also explained five forms of interaction between dimensions consisting of non-interactive, suppressive interaction, conditional interaction, integrative interaction and adaptive interaction. From these different views on sustainability concept and the interactions between dimensions, designing a sustainability course without concerning its definition will affect the course effectiveness. This is due to the contradiction of sustainability definition in each view. Therefore, teachers or course coordinators have to find their mutual understanding on the concept of sustainability.

Another characteristic for effective sustainability incorporation can be interpreted through the differences of sustainability responses in education presented by Sterling (2005). The study outlined accommodation, reformation and transformation as type of responses and each response describes different state of education in incorporating sustainability. For instance, designing a sustainability course for an engineering curriculum that has already existed might create some problems. A principle of sustainability that is embedded in the sustainability course is frequently contradicting to the existing educational paradigm. A principle such as environmental assessment at the end of engineering activities that is practiced in the existing educational paradigm is oppose to the principle of environmental prevention that limits engineering activities. Therefore, there is a need to make some changes in the educational paradigm and practice.

As the mentioned in Chapter 5, the concept of sustainability is too complex to fit in a single sustainability related course. Frequently, the knowledge of sustainability incorporated in a single course is limited and insufficient to provide engineering students with `sustainability ´attributes. It aims to connect engineering profession to the concept of sustainability, not to the extent for conceptualising or even further, to implement the knowledge of sustainability into engineering solutions. Therefore, a systematic reformation or transformation in curricula is needed to optimise the potentials to incorporate sustainability across courses and programs.

One of the characteristics of effective sustainability incorporation is by employing student centred learning as teaching strategies. All three cases (see Chapter 7) included various kinds of student centred learning such as Problem-based Learning, Research-based learning, industrial or site visits, community services and competitions. For instance, the analysis on students learning outcomes shows that majority of students from Case B are able to connect environmental, social and economic issues with the concept of sustainability, develop several skills that are related to sustainability, develop a “holistic/systemic approach” up to the basic level and have strongly positive attitudes towards all issues in sustainability. The students highlighted in the research findings that there are several factors such as participation in group discussions, participation and contribution in group project that highly contributed to student learning outcomes. The followings are the proposed characteristics of student centred learning strategies that have potential for effective course design:

i) Problem-based learning

Teachers or facilitators provide a problem that explicitly incorporates sustainability. The incorporation could be contextualised into the core problem or written in a problem description as a part of the concerned issues. In addition, the principle of sustainability needs to be highlighted along the process of making decision and developing solution. In the process of group facilitation, the teacher who’s taking role as a group facilitator is recommended to steer the group progression and discussion to be aware of issues related to sustainability. At the same time, the teacher can use the medium to share knowledge and understanding. The medium for knowledge sharing in a group discussion is not only between group members and students-teacher but it can be extended through external community of practice e.g. in-field engineer, participation. At the end of learning process, teacher has to be explicit in stating the requirement to include sustainability issues in students´ progress report and final report.

ii) Project-based learning

In a project-based learning, the project proposals have to either solely or partly address sustainability. The proposals can be either from the teacher or students or industries. Later in development process, sustainability can be included in the process of problem identification and analysis, product design and test, and product evaluation. Similar to problem-based learning, the teacher facilitates student´s progress in terms of developing a project to make sure sustainability is incorporated. It is recommended for the teacher to encourage students to build a network and collaboration with external community of practice e.g. industries and other universities.

iii) Case-based learning

For this type of teaching strategy, it is recommended for a teacher to provide a case or a collection of cases which is based on real world issues related to sustainability. Through the cases, students are driven to include sustainability as a perspective to understand the cases and the perspective is incorporated along the process of identifying the problems, conducting analysis, and proposing engineering solutions/reflections.

iv) A competition

Competition is one of the methods can be employed to incorporate sustainability in engineering education. However, there is a limitation for a teacher to align the objectives of the competition with learning objectives if the teacher didn't have the autonomy. It is important for the teacher and students to make sure that the objectives of the competition are aligned to learning objectives so that the project for competition is a benefit to the course and student learning is undistracted.

As an alternative to the limitation, teachers and students from several classes can collaboratively organize a competition that provides a challenge solely/partly addressing sustainability issues. Competition will create a competitive environment amongst students to working on their project and at the same time learning the knowledge of sustainability. The students also are driven to apply several theories to create the best solution for their project and gain several skills related to sustainability. In addition, through competition students have opportunities to build collaboration with community of practice.

v) An industrial visit

Organizing an industrial visit as a medium that connects engineering students with engineers-in-fields is a benefit for student to exchange and learn sustainability knowledge and practices. It creates learning environment that is focused on the application of sustainability principles in industries and connecting them with the role of engineers for global sustainability. In the visit, students can organise several learning activities e.g. interview sessions, which could help them to understand the current practice of industries and engineers for sustainability.

vi) A community service

There are so many ways for students and teacher to organize or participate in a community service. They could organize an awareness campaign (poster presentations, talks and etc.) to local community or organize a seminar for pupils in high schools or activity that promotes sustainability principles in living places. In a community service, students as volunteers can share their knowledge of sustainability to the participants which is entirely based on their very own approaches.

Based on the presented cases in Chapter 6 and Chapter 7, incorporating sustainability in students learning activities is one of the characteristics of an effective course design. Table 9.2 depicts characteristics of the proposed students learning activities.

Table 9.3 Characteristics of student learning activities

Student learning activities	
Peer teaching on thematic of sustainability	i) Create casual learning environment ii) Students manage their own learning and control learning pace iii) Share understanding in a small group iv) Students are the master of the topics
Interviewing sustainability experts	i) Experience the process to prepare an interview session ii) Conduct an interview session iii) Meet experts from various disciplines
Communicating to community of practice	i) Experience the process to prepare an interview session ii) Meet several engineers from sustainability field iii) Students learning sustainability from perspective engineering as a profession
Establishing networks with \`external´ peers in sustainability	i) Collaborate with various organizations ii) Meet new community of practice iii) Share knowledge and understanding from different contexts iv) Initiate networks amongst students
Preaching the concepts of sustainability	i) Collaborate with facilitator ii) Create a medium for preaching iii) Students are the master of the topics iv) Share knowledge and understanding in different kinds of setting and context
Participating in research development on sustainability	i) Experience the process to conduct research ii) Contribute to the body of knowledge iii) Gain learning outcomes along the process
Participating in students´ conference on sustainability	i) Experience the process to prepare an article ii) Meet several communities in sustainability field iii) Share the knowledge with other participants

9.6 Overall conclusion

Sustainability is a concept where the equilibrium state of the three dimensions (environmental, social and economic dimensions) in indefinite time and equity between the intergeneration and intra-generations are concerned. Therefore, incorporating sustainability in engineering education has to be part of the efforts to achieve global sustainability. Future engineers have to be equipped with attributes that require for sustainability. By adapting a basic design cycle to the overall research methodology, this research has been carried out in four phases. First three phases comprised process of analysis, design and development, and the last phase for implementation and evaluation processes. There were several research methods employed in the research phases, it included qualitative research design and mixed methods research design.

Sustainability incorporation in engineering curricula can be represented in five dimensions. Model, approach, orientation, theme and component are the dimensions that provide understanding on the existing practices in higher education on incorporating sustainability. The current university practices that solely focus on environmental dimension should not undermining the other two dimensions and under-represented the importance of inter and intra-generations equity.

Both universities are the evidence of the incorporation. It shows that the existing engineering curricula can adapt a general concept of sustainability incorporation. It is also an evidence of the contextualization of sustainability concept that is complex and covered a wide range of disciplines into specific area of learning. Through several research approaches, it is evidence to the effectiveness of employing student centered learning for the incorporation. Problem-based learning, project-based learning, case-based learning, a competition, an industrial visit, and a community service are the learning approach presented in this research.

The learning activities such as peer teaching on thematic topic of sustainability, interviewing sustainability experts, communicating to community of practice, establishing networks with `external´ peers in sustainability, preaching the concepts of sustainability, participating in research development on sustainability, and participating in students´ conference on sustainability can be characterize as learning that effective for sustainability incorporation.

9.7 Recommendations

The following are recommendations for program coordinators/developers, course coordinators/developers and engineering teachers to incorporate sustainability in engineering curricula. The recommendations are based on research findings from all phases, the experiences faced along the research processes and the framework development process.

Program coordinators/developers

The effort to incorporate sustainability into the program level involves participation and collaboration of many persons. For program coordinators/developers in Malaysian higher education, any changes on engineering curricula have to be aligned with requirements set by Engineering Accreditation Council for program accreditation and aligned with school's or department´s visions. Therefore the requirements (the minimum level/amount of competencies) are fulfilled and the quality of program is recognized by other learning institutions and industries. The biggest challenges for program coordinators are to mutually define sustainability and determine sustainability components (competencies) that are aligned and represent the objective of the incorporation. The program coordinators have to work collaboratively to define sustainability by limiting or eliminating contradictions and agreeing on a sustainability definition that represents the program. After the concept of sustainability has been defined, program coordinators have to determine the components of sustainability (competencies) that are considerably important as attributes for the students. The determination processes are built on the sustainability definition. It has to meet the needs of accreditation purposes and objective incorporation. Next, course coordinators are recommended to conduct program inventories in order to identify what are the components needed to be incorporated and empowered. Later, course coordinators have to manage the components of sustainability based on the analysis of the inventories, and decide the components that need to be part of learning objectives across all/partly engineering courses.

Course coordinators/developers
For course coordinators or developers that have intention to incorporate sustainability into their existing engineering course, it is important to be aware of the existence of contradictions in terms of educational paradigm between conventional and sustainability incorporated courses. It is a part of course designs to limit the contradictions even though sustainability has been incorporated into the context. In that sense, some of sustainability principles will be compromised and under-represented if the contradictions still exist. Therefore, course coordinators have to check-in-balance between the existing educational paradigm and the principles that are established in sustainability concept.

Engineering teachers
Incorporating sustainability for the first time in teaching can be confusing for teachers and students. This is due to the concept of sustainability that is complex and covers a wide range of disciplines. It is recommended for teachers to do team-teaching with experienced teachers, so that the incorporation goes smoothly in the course. Based on the research findings, most teachers incorporated sustainability systematically into their courses in all components of curriculum but assessments. Frequently teachers are very much focused on assessing students´ engineering competencies and give lack of stress on sustainability competencies especially students´ sustainability skills. Therefore, it is recommended for the teachers to assess students´ sustainability competencies. The research has proven the use of conceptual maps and procedural diagrams in assessing students learning outcomes in terms of knowledge and skills.

9.8 Future works

Conducting research in three huge areas of research, i) sustainable development and sustainability, ii) engineering education, and iii) curriculum design, has created several questions that need to be answered. Each question has potential as a point of departure for future works.

i. Impacts of the proposed framework on students learning outcomes.

   In part of the research phases, the proposed framework has been evaluated in terms of its deliverability and practicality aspects. The evaluation was conducted to get feedbacks from teachers and course coordinators so that the framework can be redesigned for improvement. However, there is another input for the improvement that takes into account the impacts of the framework on students learning outcomes.

ii. Empowering the under-represented dimension of sustainability in engineering education.

   Sustainability is defined as an equilibrium state of environmental, social and economic dimensions. Therefore, the under-represented dimension in engineering education is needed to be identified and empowered. Conducting research in this area could contribute to the effectiveness of sustainability into the existing engineering curricula.

iii. The impacts of different type of approaches on learning sustainability.

This study has explained the impacts of several teaching strategies on students learning outcomes which include knowledge, skills and attitudes. However, there are some limitations of the research which demand future works. For instance, investigating the impact on students learning experience which could explain the ways the students organize sustainability knowledge and mastery sustainability skills.

iv. Procedural diagrams for assessing sustainability skills

This study has presented the potential of using procedural diagrams to assess sustainability skills amongst engineering students. The tool has adapted a linear process of design to categorise the process of developing an engineering solution that aims for sustainability. However, the process of developing an engineering solution is not linear, it is a dynamic process. Therefore, conducting a research to develop a tool that adapts procedural diagrams and dynamic process of design could improve the assessment process of sustainability skills in engineering education.

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Index of tables

Index of figures

Appendix A

A framework to incorporate sustainability in engineering curricula

A.1 Introduction

The framework for sustainability incorporation depicts in figure A.1 is constructed from the research findings taken from research phase one to research phase four. It consists of four phases.

Phase I – Mapping sustainability competencies

To begin, course developers identify the competencies related to sustainability that outlined as requirements for accreditation by accreditation bodies, school, and program. Later, the course developers mapping the competencies that are incorporated in the engineering courses, so that they are able to identify the competencies need to be incorporated. Cumulatively the competencies for every courses are fulfilled the requirements for the program accreditation and therefore the alignment of competencies from accreditation bodies, school level, program level to school level is important.

Phase II – Contextualizing sustainability

Phase two is developed to contextualize the complex and broad concept of sustainability that align with the course aims that have been mapped in phase 1 and/or compatible to the existing learning objectives. The phase is divided into three components which are approaches, sustainability competencies and key sustainability themes.

Phase III – Structuring course

In this phase, course developers decide the main structure (if applicable) of the course. The structure can be characterized into two types of model and two types of orientation. The models are stand alone and integrated, while the orientations are disciplinary and interdisciplinary.

Phase IV – Integrating sustainability in course planning

Phase four is developed to integrate sustainability in course planning by adopting the employed curriculum model and align with outputs from phase 2 and phase 3. Basically, the integration is made on course learning objectives, teaching strategies, learning activities and assessment methods. Finally, the course developers will align each component in the course planning.

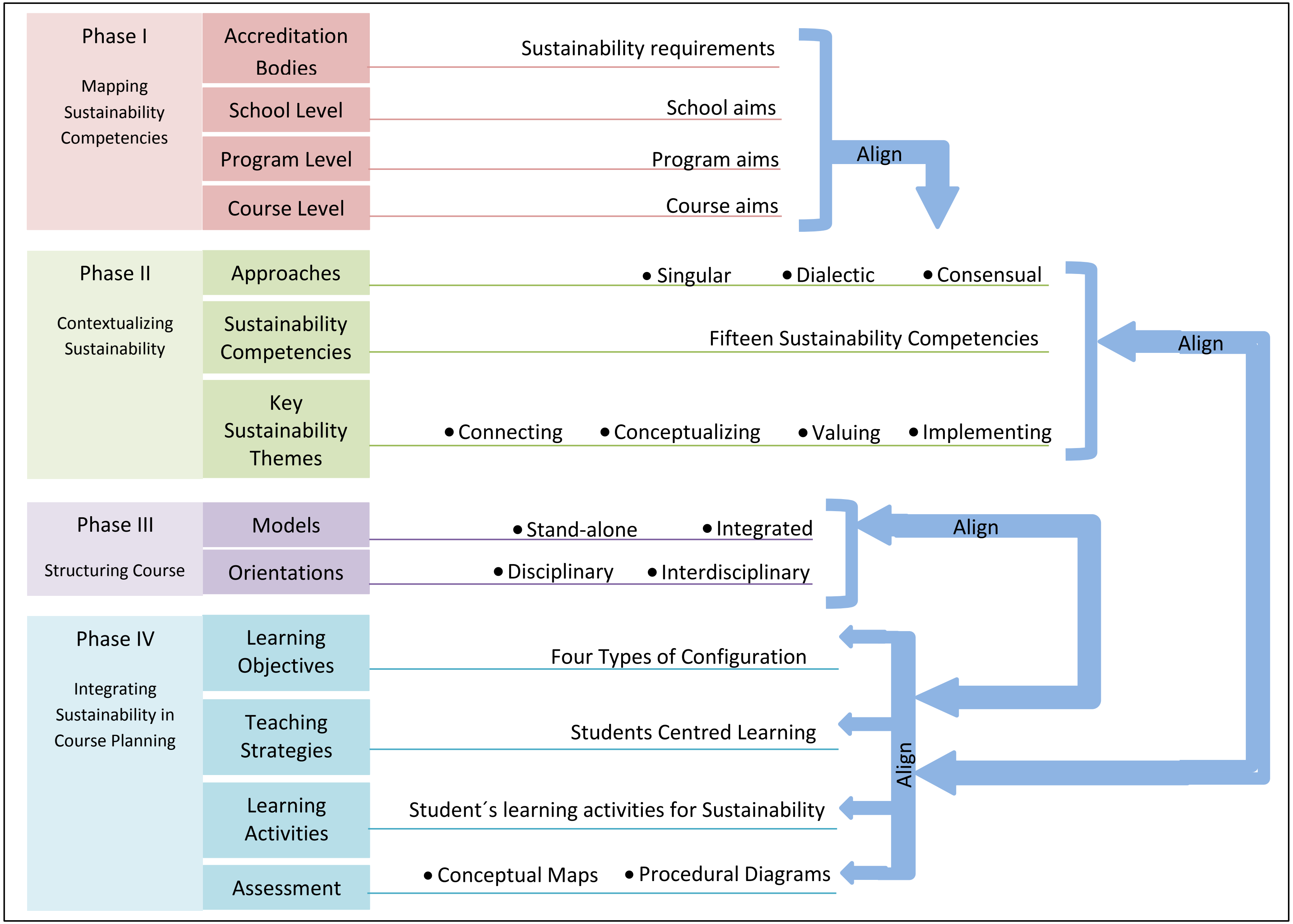


Figure A.1 The framework to incorporate sustainability in engineering curricula

A.2 Mapping Sustainability Competencies

Introduction: As Outcome-based Education (OBE) is employed in Malaysian education system, all programs and courses are designed to achieve the University/Institution aims and School objectives. The courses particularly will offer structured learning objectives (Course Learning Outcomes) which reflect to the Program objectives or Program Learning Outcomes. Therefore to incorporate sustainability into the existing curricula, managing sustainability competencies is important.

Explanation: To manage sustainability competencies, the expected sustainability competencies for the visionary course have to be aligned to the expected sustainability competencies outlined by accreditation bodies and planned by the school. The alignment of sustainability competencies can be done by mapping the competencies from all level (Accreditation bodies' level, school level, program level and course level).The flow diagram bellow shows how the four levels are mapped and influenced the process of refining sustainability competencies in every level, program planning and course planning.

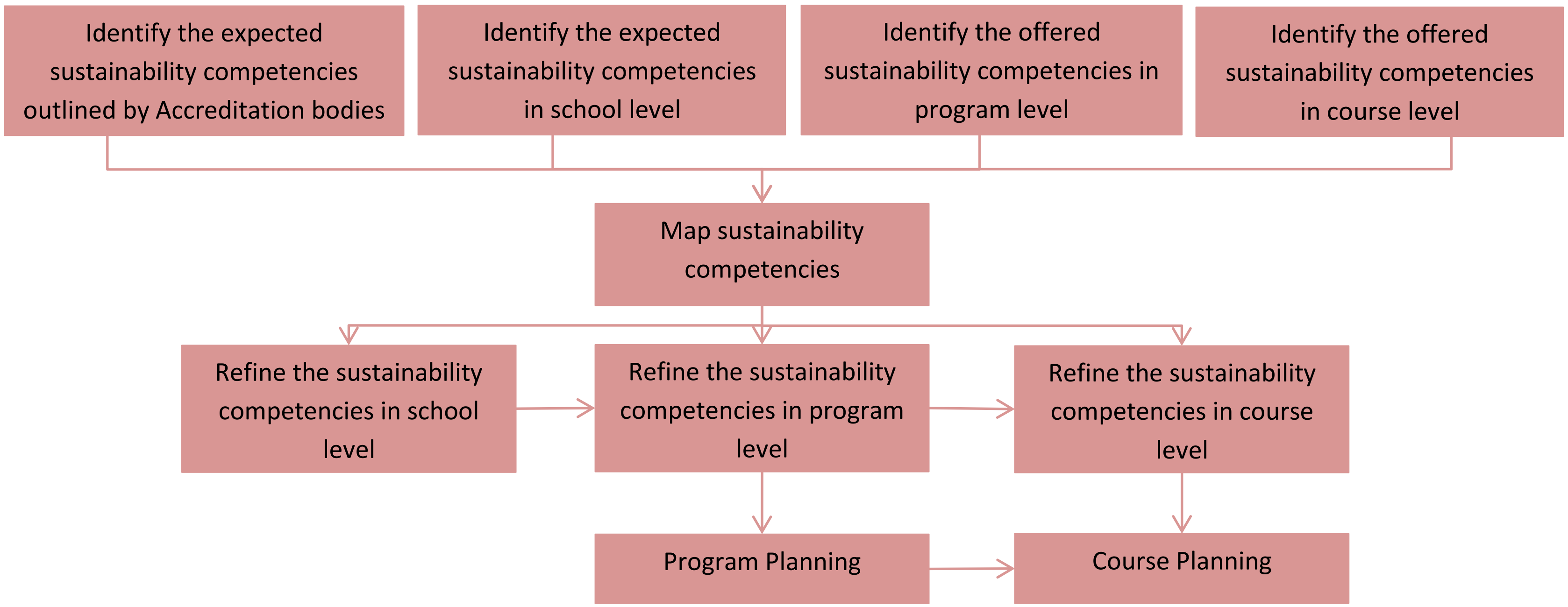


Figure A.2 The process of competencies mapping

Table below shows an example of using a matrix that outlining the sustainability components as a reference to map the expected sustainability competencies that stated by the accreditation bodies and other levels.

Table A.1 Matrix for mapping sustainability competencies

Sustainability dimensions			Sustainability components	Accreditation bodies	School level	Program level	Course level
Environmental			Environmental management				
			Environmental assessments				
			Resources				
	Economic		Green/Eco technology				
			Economic (Profits)				
		Social	Quality in Engineering				
			Stakeholders				
			Social rights/value				
			Equity				
			Citizenry				
			Culture				
			Empowerment of engineer				
			Holistic app/systemic app				
			Global issues				
			Local issues				

To be filled by course developers

Refining the sustainability competencies in the course level

Table A.2 Matrix for refining sustainability competencies

Sustainability dimensions			Sustainability components	Course level (Current version)	Course level (Refine version)
Environmental			Environmental management		
			Environmental assessments		
			Resources		
	Economic		Green/Eco technology		
			Economic (Profits)		
		Social	Quality in Engineering		
			Stakeholders		
			Social rights/value		
			Equity		
			Citizenry		
			Culture		
			Empowerment of engineer		
			Holistic app/systemic app		
			Global issues		
			Local issues		

To be filled by course developers

A.3 Contextualizing Sustainability

Introduction: As the concepts of Sustainability are broad and included three dimensions which are environmental, social and economic. This framework proposed to contextualize the concepts of sustainability therefore the desired sustainability competencies could align with the identified course aims and/or compatible to the existing learning objectives. This framework proposed, in order to contextualize the concepts of sustainability, it is suggested that there are three main components could be used as a platform.

The following figure shows that approaches to sustainability, sustainability competencies and key sustainability themes are the possible platform for teacher to contextualize sustainability into their context.

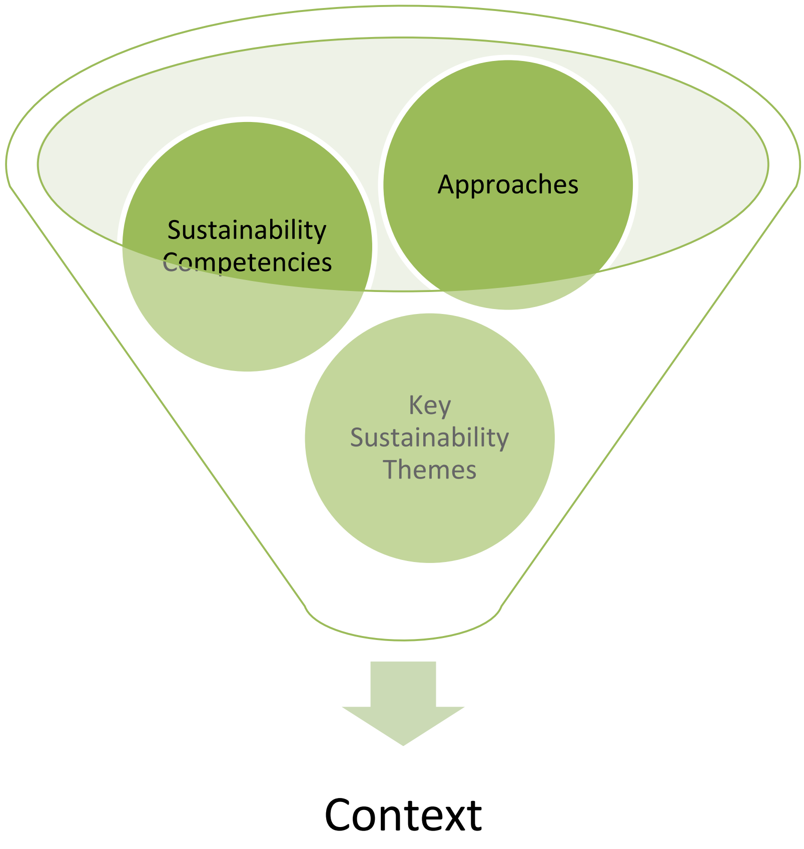


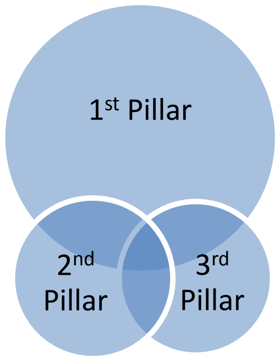
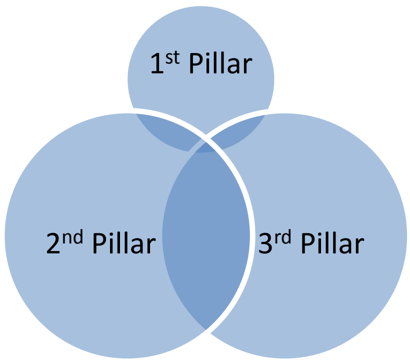
Figure A.3 A concept of sustainability contextualization

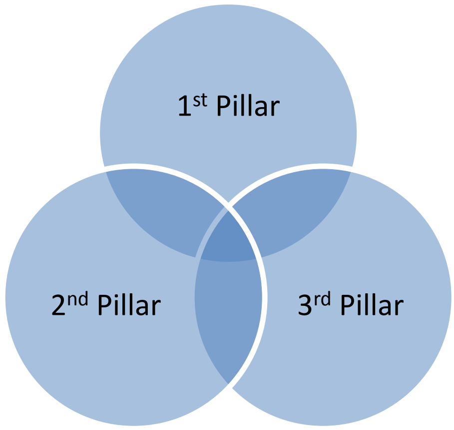
A.3.1 Approaches to Sustainability

Introduction: Sustainability is defined beyond than the incorporation of the three dimensions; environmental, social and economic. It is about balancing the incorporation of those three key dimensions. However, the balance of incorporation of sustainability is not necessary tied to a single course but rather to program as a whole. A sustainability course that emphasizes the environmental dimension will be in a perfect equilibrium with other sustainability-related courses that emphasize the other dimensions.

Explanation: The following matrix shows approaches to sustainability. The approach could be singular, dialectic or consensual. Ideally the approaches are proposed to make the concepts of sustainability compatible to the existing engineering curricula by emphasizing a single pillar or couple of pillars.

Table A.3 Matrix of approaches to sustainability

Approach		Details
Singular		The singular approach is described as sustainability courses that emphasize a specific pillar instead of a holistically blend of the three pillars together in a single course.
Dialectic		The dialectic approach is defined as an approach that blends two pillars of sustainability to be the major learning component. *A combination of the environmental with the social perspective is one of the possible combinations that can be made as an approach to sustainability.*

Consensual		The consensual approach is an approach where learning objectives and course contents for sustainability course are fairly balanced in the integration of three pillars.

A.3.2 Key Sustainability Themes

Introduction: Incorporating the broad concept of sustainability into the existing engineering curricula is a challenging process. The contents of the three dimensions, environmental, economic, and social, are too broad to fit into a single engineering course or numbers of engineering courses. Despite these challenges, changes have to be done.

Explanation: Key sustainability themes can be a useful method to integrate the three dimensions into the existing engineering curricula. The sustainability themes are proposed without intention to narrow down the concept of sustainability; however, it is an effort to put the concept into a visualize representations appropriate for engineering education. There are four key sustainability themes which are illustrated in the figure A.4.

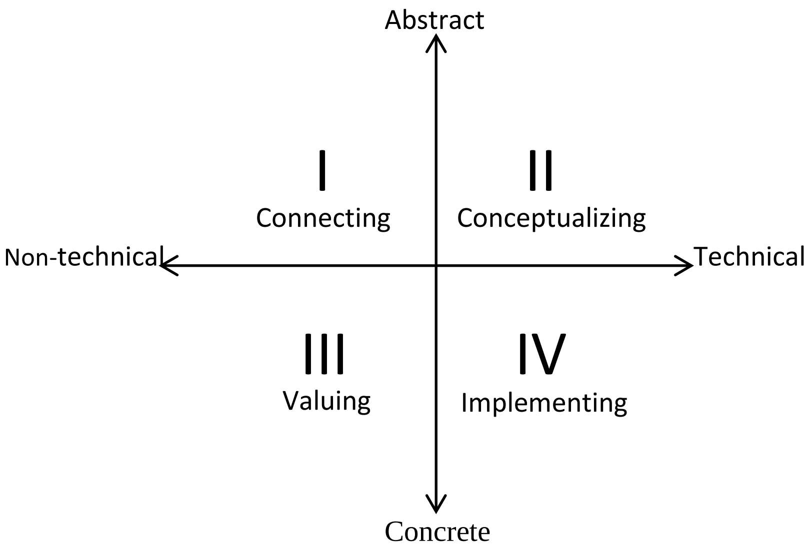


Figure A.4 The key sustainability themes for engineering education

Table A.4 Matrix of theme 1 and theme 2

	Theme	Details
I	Connecting sustainability to the engineering profession	Theme I encompasses the elements of sustainability which are the fundamental knowledge of sustainability, the engineering ethics/moral, the empowerment of engineer, the global issues and the local issues. These sustainability elements that focus on non-technical contexts and abstract concepts are commonly integrated in engineering education as an introduction for engineering students to view the concepts of sustainability. The Theme I contains the elements that are a basic knowledge, principles, concepts and issues that give a general picture of SD. These elements are important information for students to understand SD concepts and we believed by connecting SD into the engineering profession, the students could increase their understanding and eventually they have a strong foundation on SD concepts
II	Conceptualizing sustainability into the engineering designs	Theme II represents the conceptualizing of SD concepts into an engineering design. The elements, which are categorized in the theme II, exemplify the integration of SD into the technical contexts and in abstract concepts. The elements are the holistic approach/integrative approach towards sustainability and the concepts of green/ecology technology. The Theme II includes the elements that are more complex, interdisciplinary oriented and high level of abstraction. The elements require students to interconnect various perspectives and approaches of SD. At the same time, the elements also require students to interrelate the elements of SD with technical perspective. Therefore, we proposed that students could gain a lot on their understanding if they could apply the SD concept in their engineering design.

Table A.5 Matrix of theme 3 and theme 4

III	Valuing sustainability in the engineering justification	Theme III includes the issues related to environment, resources and eco-system, social rights/values, social equity, citizenry, economic and stakeholders. These elements are predominantly categorized as non-technical contexts and concrete concepts for engineers. The Theme III encompasses the elements of sustainability that are more complex and more often create conflicts when it comes into implementation compare to the Theme I and the Theme II. In order to understand these elements, students not only learning on the factual knowledge and conceptual knowledge but experiencing and employing the elements into engineering process i.e. an evaluation process. Valuing these elements in any engineering evaluation process can be a huge challenge to engineering students and even engineers. However, these elements are crucial to be put in consideration of the engineers to justify their decisions. We proposed that these elements are integrated in engineering curricula and designed therefore students could value it in their engineering justification.
IV	Implementing sustainability into the engineering solutions	Theme IV represents the implementation of SD concepts into the engineering solutions. The Theme IV encompasses the elements such as environmental assessments, quality in engineering as well as green or ecology technology. The criteria of this theme predominantly focus on integrating elements of sustainability into technical contexts and concrete concept. These elements also could be categorized as procedural knowledge. The knowledge that requires students have to experience how to apply and understand where to use it. Thus by implementing the knowledge such as environmental assessments in engineering solutions, students will obtain the knowledge efficiently and gain the skills of employing the knowledge into engineering contexts.

A.3.3 Sustainability Competencies

Introduction: In this section, the framework propose a series of sustainability competencies which are developed from intensive analysis on the concepts of Sustainability in Engineering Education and Sustainability courses from several countries. The competencies are organized in terms of Sustainability components therefore it could reflect to the three major dimensions of sustainability (Environmental, Economic and Social dimensions).

Explanation: The following table shows examples of Sustainability competencies that could be integrated into the engineering curricula. The competencies are clustered according to the Sustainability components and Sustainability dimensions.

Table A.6 Matrix of sustainability competencies

<table>
<tr><th colspan="3">Sustainability dimensions</th><th>Sustainability components</th><th>Competencies (Example)</th></tr>
<tr><td rowspan="4">Environmental</td><td rowspan="3"></td><td rowspan="5"></td><td>Environmental management</td><td>Reduce the use of materials and chemical that accumulate in the environment
Valuing the environment
Managing waste
Eliminate all waste products
Eliminate/minimize the use of hazardous material
Pollution precaution</td></tr>
<tr><td>Environmental assessments</td><td>Apply environmental impact assessment tools
Monetary valuations of the environment
Compensate pollution
Use life cycle thinking in engineering activities</td></tr>
<tr><td>Resources</td><td>Reduce material and energy intensity development
Conserve and improve natural ecosystems
Improve energy efficiency
Improve resource efficiency
Minimize depletion of resources</td></tr>
<tr><td rowspan="3">Economic</td><td>Green/Eco technology</td><td>Develop clean technology
Employ ecological design
Develop technology and systems that work across a range of different scales
Following green engineering</td></tr>
<tr><td rowspan="2"></td><td>Economic (Profits)</td><td>Reduce material costs
Minimize use of materials
Increase production efficiency</td></tr>
<tr><td>Social</td><td>Quality in Engineering</td><td>Improve efficiency of products</td></tr>
</table>

			Stakeholders	• Engage to stakeholders to identify problems and issues • Listen to demands • Actively engage to stakeholders in developing of engineering solutions • Reflects on stakeholders views
			Social rights/value	• Considering the right of society to inherit sufficient to generate a level of welfare • Protecting human health and well being • Providing public safety • Contribute to social context • Communicate effectively with society at large • Access legal issues
			Equity	• Balance between inter and intra generations equity • Equity in resources allocation • Equity between the poor and the rich • Equity in material growth • Equal right for development • Long time scale of impact • Equal opportunities to effected people • Reduce gaps • Acceptable quality of life • Value future as well as current generations
			Citizenry	• Engineer participate in decision making as citizens • Listen to the demands of citizens • Counselor to citizenry in general
			Culture	• Include the culture knowledge and relate it with technology • Contribute in different culture • Meet the need of culture • Cognizant of cultures in engineering process
			Empowerment of engineer	• Gain full autonomy over decision making
			Holistic approach /systemic approach	• Balance environmental, social and economic factors • Seek balanced solutions • Problem solution based primarily on human needs and ecosystem viability • Integrate view of the aspects of social development, economic growth and environment protection • Adopt a holistic, cradle-to-grave approach

				• Systematic assessment of all relevant expenses
			Global issues	• Global environment discourse • Security, peace and trade, hunger, shelter and water
			Local issues	• Cognizant of local aspirations • Interact to local • Identify potential impacts

A.4 Structuring Course

Introduction: In structuring a Sustainability course, there are models and orientations that should be part of the process. The main objectives of this exercise are to explain how each of the models could effects the existing engineering program and engineering courses, and how the orientations could effects process to formulate learning objectives and to develop course contents.

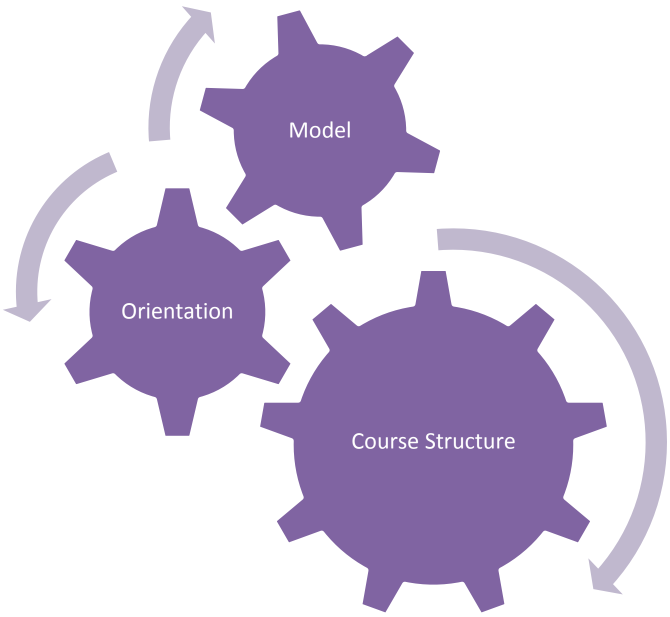
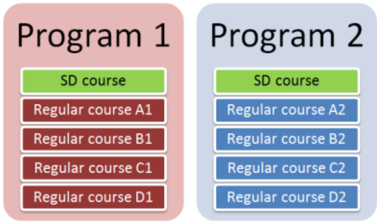
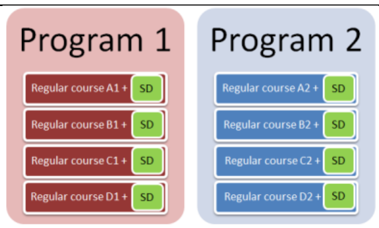


Figure A.5 A concept for structuring sustainability course

A.4.1 Models

Introduction: There are two basic models for structuring a course. The models are stand-alone model and integrated model.

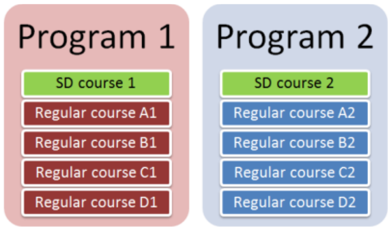
Table A.7 Matrix of sustainability course models

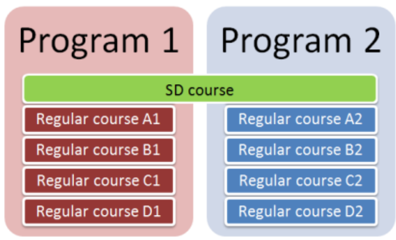
Model	Details	
Stand-alone model		• Generally, this model is applied at an early stage of curriculum transformation where a university introduces sustainability courses either incorporated or separate into the programs. • The stand-alone model means that a course will be designed and constructed to provide understanding of sustainability with no intention to integrate this knowledge into the existing engineering courses. • The advantage of this characteristic is that it is believed that the course can be applied to other programs and faculties without much adaptation. • The figure illustrates a stand-alone model that is applied to a SD course for Program 1 and Program 2.
Integrated model		• Conceptually, the integrated model is a model where sustainability elements integrate into regular or traditional engineering courses. • This model requires course designers to revise and reconstruct engineering courses and adapt the sustainability concept to the needs of the curriculum. • Therefore, the sustainability concept will not only be introduced to engineering fields but it will purposely be designed to the application, evaluation and synthesis levels.

A.4.2 Orientations

Introduction: Orientation of a course is focuses on how learning objectives are formulated and how the choice of content is made from the pool of discipline knowledge.

Table A.8 Matrix of sustainability course orientations

<table>
<tr><th>Orientation</th><th colspan="2">Details</th></tr>
<tr><td>Disciplinary</td><td>The disciplinary orientation only focuses to provide learner with specialized skills and concepts in a field without any intention for integration</td><td>

The figure shows sustainability courses that are constructed to fit within specific disciplines or a particular program.
Normally, the programs offered at university are discipline oriented and the courses have been constructed to be relevant and to satisfy the program’s learning objectives.
In the field of engineering, most university has divided engineering disciplines into several programs such as mechanical engineering, electrical engineering, chemical engineering and civil engineering.
</td></tr>
<tr><td>Interdisciplinary</td><td>The interdisciplinary orientation “purposely brings together the full range of disciplines in the curriculum and uses a full array of discipline-based perspectives”</td><td>

The impact of a course with interdisciplinary orientation depends on the range between one disciplinary and other disciplines.
A sustainability course that caters all four conventional engineering disciplines, mechanical, electrical, chemical and civil disciplines, has to deliver and satisfy all program learning objectives.
Unlike combining two or three disciplines in the same pool of knowledge, constructing sustainability courses for a wide range of disciplines demand strong corporation and agreement on selecting learning objectives as
</td></tr>
</table>

		well as course contents. • The figure illustrates position of a sustainability course is bridged from Program 1 to Program 2. • The course can be single sustainability course or more, but implementation of the course(s) have to cross disciplines and no changing or rearranging of learning objectives are required according to specific discipline.

A.5 Integrating Sustainability in Course Planning

Introduction: In Malaysian higher education system, most course developers employed constructive alignment model as a basis to construct engineering curricula. The following figure depicts the incorporation of sustainability in the constructive alignment model. The incorporations are made to the existing curriculum objectives, teaching activities, learning activities and assessment tasks.

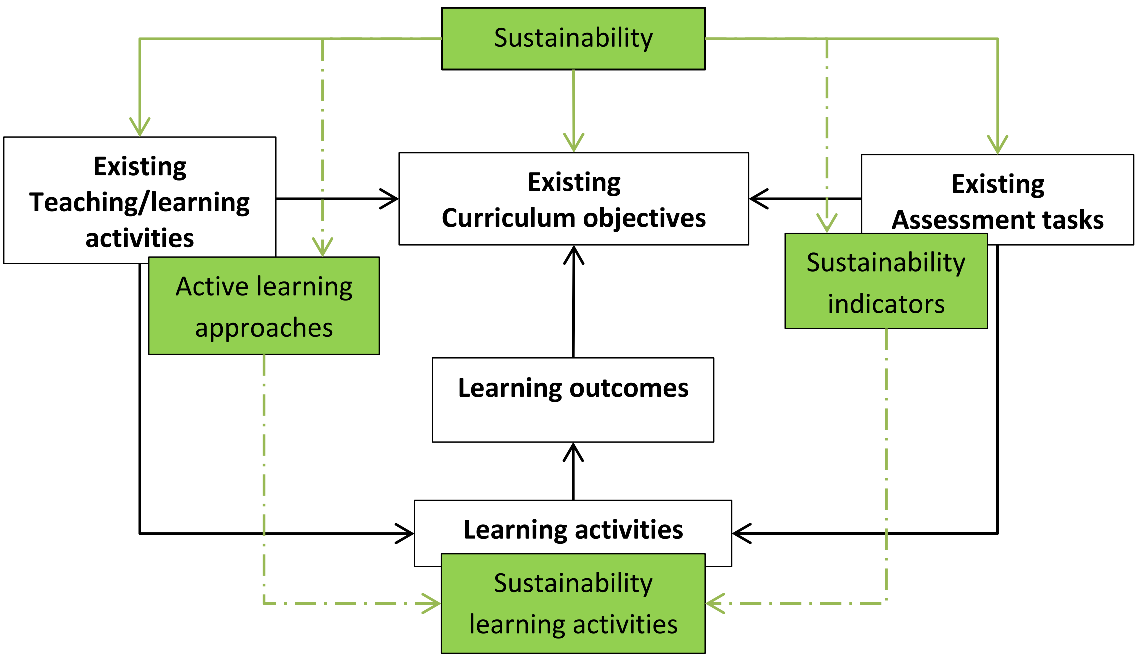


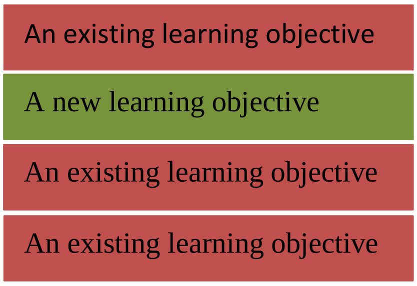
Figure A.6 A concept of sustainability integration in course planning

A.5.1 Learning Objectives

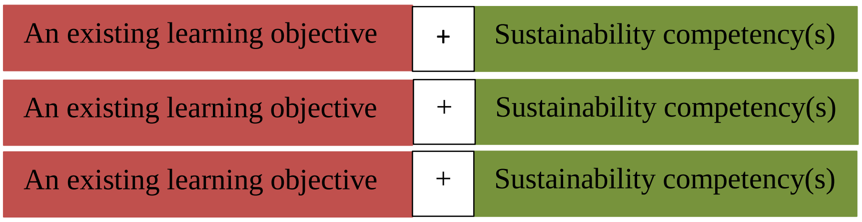
Introduction: As the concept of sustainability incorporation ties on the constructive alignment model, learning objectives is a major entity that influences the design of teaching strategies, learning activities and assessment methods. Learning objectives are constructed by addressing and complying program learning outcomes as well as the requirements set by accreditation bodies/councils.

Explanation: The formulation of learning objectives in the existing engineering course could be in the following configurations

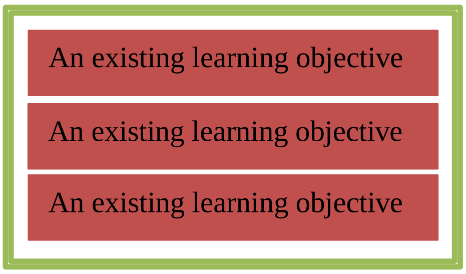
i. Add a new learning objective(s) into the existing learning objectives that entirely aims to attain Sustainability competencies.



ii. Add a sustainability competency(s) as a minor competency into the existing learning objectives



iii. Revise the existing learning objectives to sound sustainability without any intention to assess the sustainability competencies



iv. Revise the existing learning objectives to entirely embrace Sustainability and Sustainability competencies are the major competencies of the course

Major: Sustainability competency(s)	+	Minor: Existing Competency
Major: Sustainability competency(s)	+	Minor: Existing Competency
Major: Sustainability competency(s)	+	Minor: Existing Competency

A.5.2 Teaching Strategies

Introduction: Organising teaching strategies are important in order to make sure that the expected learning outcomes (formulated in the learning objectives) can be achieved by students. Employing a student-centred approach is highly recommended and the approach provides positive effects on students learning outcomes. As a teacher in the main stream where traditional-teaching is a predominant approach, integrating a student-centred approach in teaching could be challenging tasks.

Explanation: The following discussions are presented to give some ideas how these teaching strategies can be employ to integrate sustainability into the existing engineering curricula.

i. Problem-based Learning

Table A.9 Matrix of sustainability incorporation in problem-based learning

Features	
Role of teacher	Facilitator
Role of students	Problem solver
Characteristics of Problem based learning – Sustainability integrated	1. Provides a problem where Sustainability is a part of it and explicitly provides/highlights issues related to Sustainability in the problem description. 2. Provides a problem that Sustainability is contextualised into the core problem 3. Highlights that Sustainability is a part of perspectives to address a problem. 4. Embeds Sustainability principles in a decision making and developing solution. 5. Provides opportunities for student to communicate to community of practices. 6. Gives some insight on Sustainability in the facilitation 7. Provides opportunities for student to build a network and collaboration with external community of practice. 8. Provides outlines that could include Sustainability as core elements in report preparation or in documentation.

ii. Project-based Learning

Table A.10 Matrix of sustainability incorporation in project-based learning

Features	
Role of teacher	Facilitator/Project Supervisor
Role of students	Project developer
Characteristics of Project – Sustainability integrated	1. Provides a proposal which is solely/partly designed to address Sustainability either funded by industries or prepared specifically for education purposes. 2. Provides outlines/guidelines for student to come out with project proposal that address Sustainability. 3. Embeds Sustainability principles in i) identification and analysis of problems, ii) product design and test, iii) product evaluation 4. Facilitate student´s progress in term of developing a project to make sure Sustainability is integrated 5. Gives some insight on Sustainability in the facilitation 6. Provides opportunities for student to build a network and collaboration with external community of practice. 7. Provides outlines that could include Sustainability as core elements in report preparation or in documentation.

iii. Case-based Learning

Table A.11 Matrix of sustainability incorporation in case-based learning

Features	
Role of teacher	Facilitator
Role of students	Student
Characteristic of Case – Sustainability integrated	1. Provides a case or collection of cases which based on real-world cases in relation to Sustainability. 2. Includes Sustainability as perspectives to understand the cases and to identify problems. 3. Provides outlines/guidelines to analyse the cases. 4. Connects the cases with their understanding on Sustainability.

iv. A competition

Table A.12 Matrix of sustainability incorporation in a competition

Features	
Role of teacher	Facilitator/Coordinator
Role of students	Participant
Characteristics of Competition – Sustainability integrated	1. Provides a challenge that solely/partly to address Sustainability. 2. Create a competitive environment on understanding Sustainability. 3. Demands the application of Sustainability knowledge. 4. Highlights the best solution(s) on the application of Sustainability knowledge. 5. Provides opportunities for participants to build a collaboration/network with community of practice.

v. An industrial visit

Table A.13 Matrix of sustainability incorporation in an industrial visit

Features	
Role of teacher	Supervisor
Role of students	Participant
Characteristics of Visit – Sustainability integrated	1. Provides a medium for knowledge exchange on Sustainability between participant and community of practice 2. Create an environment where exemplify the application of Sustainability principles in industries. 3. Connects Sustainability into professionalism perspectives. 4. Provides opportunities for participants to have discussion about Sustainability practices with engineers and community of practice.

vi. A community service

Table A.14 Matrix of sustainability incorporation in a community service

Features	
Role of teacher	Supervisor
Role of students	Coordinator/Volunteer
Characteristics of Community Service – Sustainability integrated	1. Provides a medium for knowledge exchange on Sustainability between coordinator/volunteer and participant. 2. Includes Sustainability as one of the elements included in the program. 3. Provides opportunities for coordinator/volunteer to create an approach in conveying Sustainability knowledge in the program.

A.5.3 Learning Activities

Introduction: Planning learning activities is one of the important tasks for a teacher in order to create and sustain students´ excitement and focus on the course. A proper planning on learning activities could gain students´ learning outcomes includes knowledge, skills and attitudes. Each kind of activity will enable different kind of learning environment, learning process as well as learning outcomes.

Explanation: The following learning activities are the examples to incorporate sustainability in engineering curricula

i. Peer teaching on thematic topic of Sustainability

This is the common activity that usually applies in an active-learning approach. This approach is always creating casual learning environment, where students have full liberty in coordinating their learning as well as controlling their learning pace. Peer teaching is actually enabling students to share their understanding on the certain topic about Sustainability in a small group. In their group, the students have to master the given topic and convey the knowledge to their peers. The group members also have opportunities to question, argue, discuss and criticize on the presented topic.

ii. Interviewing Sustainability Experts

In this learning activity, students have to go through a process for undertaking interview sessions with experts. A process where they have to clarify the objectives of the sessions and what kind of information that they are looking for. They have to prepare some set of questionnaire either for semi structured interview or fully structured interview. Students also have to carefully identify their prospective interviewee (respondents) therefore the questions are connected and relevant to the respondents as well as achieving their aims. In the interview sessions, students will get valuable perspectives of Sustainability concepts and principles from the experts. They could also connect their understanding into diverse academic disciplines.

iii. Communicating to Community of Practice

For this learning activity, students are likely will gone through the same process to set an interview session with Sustainability experts. It is a good opportunity for student if they could meet several engineers who are working in Sustainability field. They could communicate and sharing their profession experience dealing with Sustainability and could help students to understand the application of Sustainability in working place. In addition, students are able to connect Sustainability into their profession or local context and able to understand how Sustainability is applied in the real-world.

iv. Establishing networks with "external" peer in Sustainability

This is one of activities that could embark collaboration between departments, schools and institutions. In this activity students are able to meet new community of practice which outside their learning circle. One of the possible medium that could provide this activity is through a competition. Despite of competitive learning environment, students also could sharing the understanding on the concept and learning from each other. They also have opportunity to initiate a network amongst them, either for social or academic purposes.

v. Preaching the concepts of Sustainability

For this kind of activity, both students and facilitator are working together to create a medium for enable students to preach the concepts of Sustainability. The medium could be a day Sustainability related campaign either for internal target groups or external. In order to preach the concepts of sustainability to others, therefore the students will learn and master the knowledge. They also will learn to convey they knowledge in different kinds of setting depend on context and situation. For example, if they run a talk to group of pupils in the school. They will convey the knowledge that understandable for the target group.

vi. Participating in research development on sustainability

Doing research in Sustainability definitely create more complex setting of learning activities compare to other types of activities. Participating in research development will make student to understand the knowledge of Sustainability deeply and could contribute into the body of knowledge. However, this activity acquires a lot of time and demands a full commitment either from the students or the facilitator. Students learning outcomes will entirely depend on research objectives or research questions and their knowledge, skills and attitudes will gain/change along the research process.

vii. Participating in students´ conference on sustainability

In this learning activity, students will connect to several communities of practice such as students, researchers, academicians, practitioners and engineers. The medium will be organised by the conference committee which can be either amongst the students or others organization. However, to participate in the conference, together students and facilitator have to produce a research article / a poster that comply with conference themes. In the conference, they could share, contribute and get update with currents discourse or debate on Sustainability.

A.6 Assessments

Introduction: There are several questions have to be put in consideration before designing assessment methods and assessment tools. Questions such as what are the purposes to assess, what to assess and how to assess should be part of the process on designing the assessment methods and tools.

Explanation: In the case of assessing Sustainability in engineering education, there are several assessment methods can be used (i.e. formative – summative, process – product, and formal – informal) which are widely used in most of education setting and disciplines. However, to design assessment tools for assessing Sustainability in engineering curricula, we would like to propose Conceptual Maps to assess student´s knowledge, and Procedural Diagram and Five-point Score to assess student´s skills.

A. Conceptual Maps

Conceptual maps are graphical tools for organizing and representing knowledge. The main features of the concept maps are:

i) Concepts, which usually enclosed in circles or boxes.
ii) Connecting line, which linking between two concepts
iii) Words on the line, which referred to as linking words

For example,

A concept map always starts with a general concept, for this case *Sustainable Development* is the general concept. It is in the top of the hierarchy of the concept. The more specific concepts are arranged in lower hierarchy, for this case are *Three P´s* and *Triple bottom line*. Both concepts are connected with arrows and *known as* as the linking word.

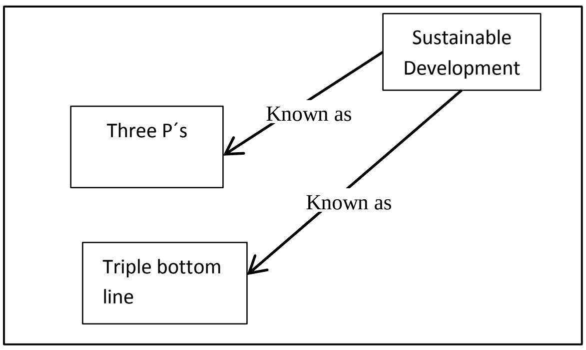


Figure A.7 A basic illustration of conceptual maps

Below is an example of the concept maps for Sustainable Development.

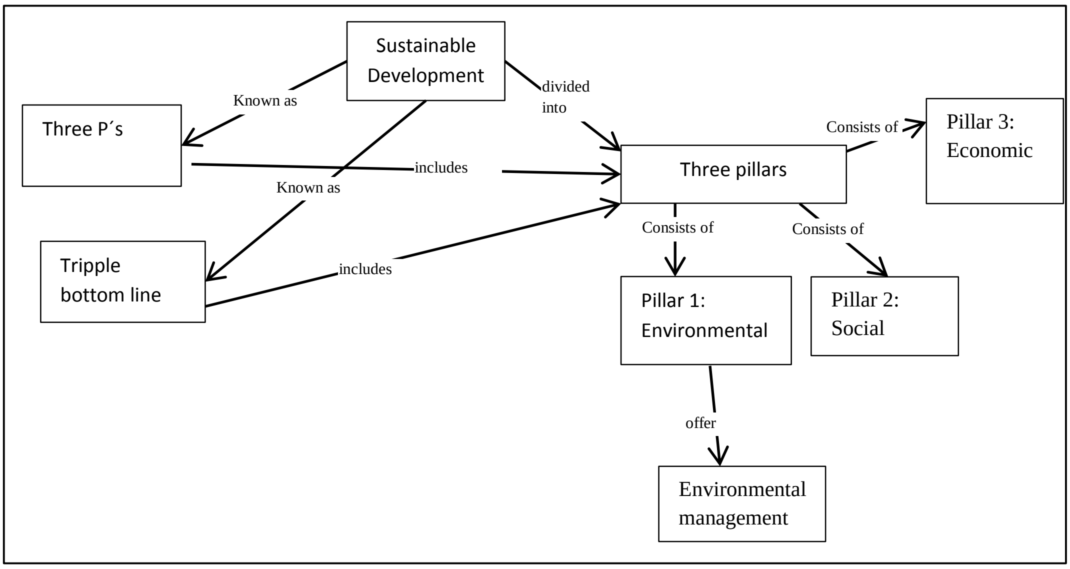


Figure A.8 An example of conceptual maps for sustainable development concept

B. Procedural diagram and self-rate procedure

Procedural diagram is graphical tool for organizing and representing a set of procedure. Usually the procedure is interpreted in skills form. The main features of the procedural diagram are:

i) Skills, which enclosed by boxes
ii) Connecting line, which linking between two skills
iii) Stages of design

For example,

Procedural diagram consists of four stages of design, which are Analysis, Design, Develop and Evaluate stages. It is always starts with the first step at the very beginning of the design process, for this case the first step is the skill to *identify the problem background*. The next step of the process could consist of a single skill or more e.g. *Analysis the problems using SWOT* and *Analysis the problems using Pro´s – Contra´s.* Both skills are connecting with arrow. In hierarchal fashion, the top skill(s) is (are) prerequisite for the skill(s) in the below.

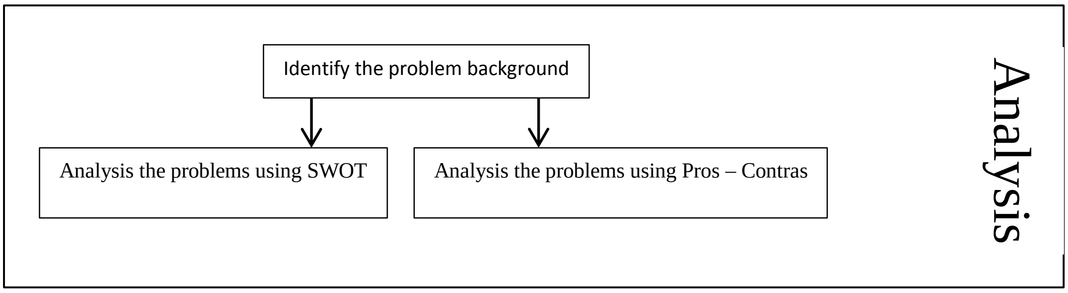


Figure A.9 An example of procedural diagrams in analysis stage

After the procedural diagram is completed, please rate yourself by referring to the five-point score. In order to rate the skills, each of the skill has to be rate in five-point score. The scores are:

Table A.15 Five-point score for procedural diagrams

Score	Level	Description
0	Unskilled	Do not have experience of the skill.
1	Basic	Experienced in applying the skill on simple task.
2	Skilled	Experienced in applying the skill on difficult task.
3	Master	Experienced in applying the skill on complex task.
4	Expert	Experienced in applying the skill on sophisticated task

Below is an example on how respondents rate the skills on the procedural diagram. The score is stated on the right side of the box. Therefore the number will indicate the skill level for that particular skill. For example, with score of three at *Identify the problem background* box indicates that the respondent experienced in applying the skill on complex task (Master level).

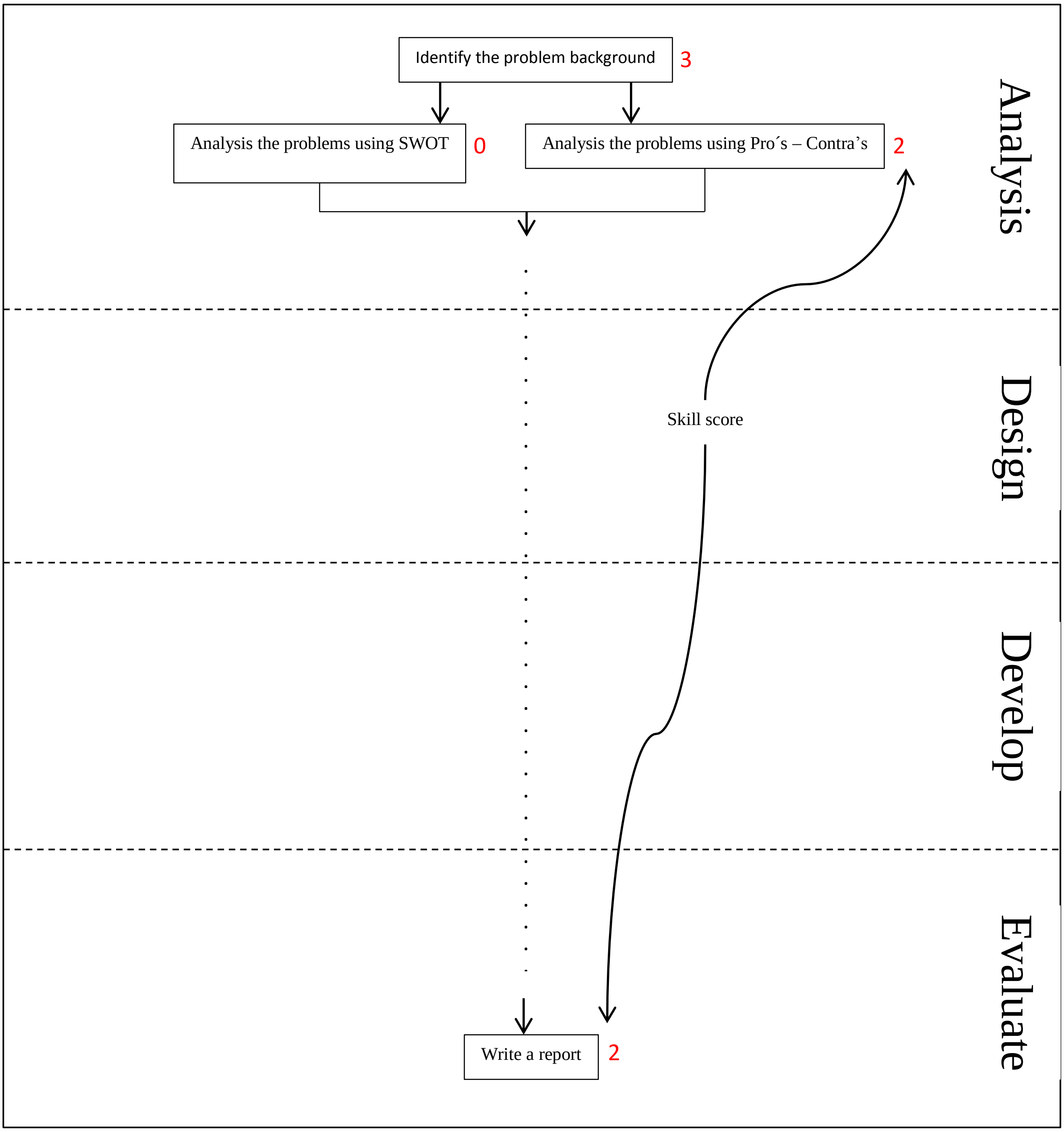


Figure A.10 An example of procedural diagrams

Appendix B

Research instruments

The following are the research instruments that have been used as a tool to gather data for research phase 1 until research phase 4.

Contents

Appendix B.1 Procedure for data collection session

First of all, I would like to share with you the overall project of my PhD. My main research project is to study the effectiveness of learning sustainability in engineering education between two types of course structures, Stand-alone and Integrated courses. Both courses are expected to produce different level of effectiveness. Therefore, in my research, I will evaluate the effectiveness of the courses by measuring students´ learning outcomes and comparing to course learning objectives.

A part of this project, I also will study the concepts of sustainability in the perspectives of engineering education and the practices.

From the research instrument that I gave to you before, there are 10 components of learning sustainability (Small laminated tags). The components are the common sustainability components offered in 15 sustainability courses. All the courses were offered in several universities in US, Europe and Asia.

Basically, this interview session is about to collect feedbacks from expert about learning sustainability in engineering education based on the ten components of learning sustainability and experiences in the field of sustainability as well as course development.

In the session, we will have three parts.

Part 1: In this part, you have to prioritize the sustainability components and at the same time you have to think aloud while you completing the task. Therefore, I will observe you completing the task and listen to your thinking.

Part 2: I will ask you a few questions to reflect back on the previous task.

Part 3: I will ask you a few questions about you experiences in the field of sustainability and courses development.

1. Brief the whole processes of the session.

    a. Task 1: Prioritize sustainability components for integrating sustainability in engineering education.

    b. Task 2: Reflection on Task 1.

    c. Interviews (If the experts are curriculum designer)

2. Ask for a permission to record the session.

3. Start the Task 1 by the following instructions.

    a. Prepare the instruments by following the illustration in figure 1.0

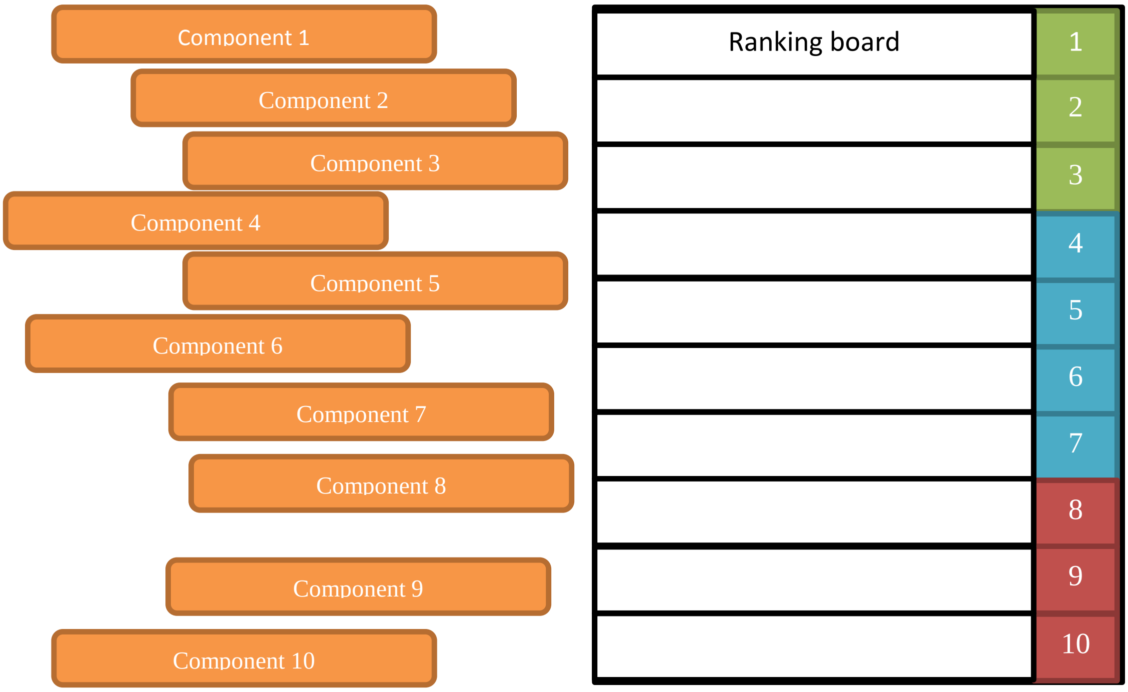


Figure 1.0

    b. Instructions: By using the cards that stating ten components of sustainability in engineering education. Please prioritize from the most important to the least important components by putting them in the Ranking Board given.

    c. For this purpose, you are suggested to think aloud while you completing the task.

    d. You are expected to complete the Task 1 within 15 minutes.

4. End the first task.

    a. Thank you for your responses. Now we move on to the second task.

5. Start Task 2 by the following questions.

    a. Why do you think component in the first rank is the most important for learning sustainability in engineering education?

    b. Why do you think components in the first, second and third are the highly important components for learning sustainability in engineering education?

    c. Why do you think component in the last rank is the least important component for learning sustainability in engineering education?

    d. Why do you think components in the rank of 8, 9 and 10 are the least important for learning sustainability in engineering education?

    e. Based on your experiences, do you want to suggest other components that important for engineering students learning about sustainability? And why you think so?

6. End the second task.

    a. Thank you for your cooperation. Now we move on the short interviews.

7. Start the interview by the following questions.

-Referring to interview questions guidelines-

8. End the session.

    a. Thank you so much. Your cooperation is really meaningful for my PhD project.

Appendix B.2 Ranking tasks

Please prioritize from the **most important** to the **least important** components regarding **learning of sustainability in engineering education** by putting one number in each box.

Most important									Least important
1	2	3	4	5	6	7	8	9	10

The fundamental concepts of sustainability	
The engineering ethics	
The knowledge of environmental management	
The knowledge of environmental assessments	
Engineering solutions based on economic aspect	
Engineering solutions based on criteria set by stakeholders	
Engineering solutions considering the resources and eco-system	
Engineering solutions in term of quality	
Engineering solutions for global problems	
Engineering solutions for local problems	

Other (suggestions) components for learning sustainability in engineering education

____

Components of learning sus.	Responses while thinking aloud
The fundamental concepts of sustainability	
The engineering ethics	
The knowledge of environmental management	
The knowledge of environmental assessments	
Engineering solutions based on economic aspect such as cost of productions	
Engineering solutions based on criteria set by stakeholders	
Engineering solutions considering the resources and eco-system	
Engineering solutions in term of quality	
Engineering solutions for global problems	
Engineering solutions for local problems	

Appendix B.3 Interview questions

– Respondents are giving feedbacks on ranking task

Why do you think component in the first rank is the most important for learning sustainability in engineering education?	
Why do you think components in the first, second and third are the highly important components for learning sustainability in engineering education?	
Why do you think component in the last rank is the least important component for learning sustainability in engineering education?	
Why do you think components in the rank of 8, 9 and 10 are the least important for learning sustainability in engineering education?	
Based on your experiences, do you want to suggest other components that important for engineering students learning about sustainability? And why you think so?	

Appendix B.3 Interview questions

– Respondents are providing overview on the sustainability incorporation in engineering curricula

Questions	Responses
Would you please tell me about your background and working experiences in the field of sustainability in engineering education?	
What do you think about education about sustainability at your university in general and in your department?	
Have you lead or participated in developing a sustainability course or reform the existing course to incorporate sustainability?	
What are the strategies that you employed to integrate sustainability into your engineering course?	
Why you choose that strategies?	
What is the main teaching strategy that you employed into you course?	
Why you choose that teaching strategy?	

Appendix B.4 Interview questions

Introduction

First of all, I would like to share with you the overall project of my PhD. My main research project is to study the effectiveness of learning sustainability in engineering education between two types of course structures, Stand-alone and Integrated courses. Both courses are expected to produce different level of effectiveness. Therefore, in my research, I will evaluate the effectiveness of the courses by measuring students´ learning outcomes and comparing to course learning objectives.

A part of this project, I also will study the concepts of sustainability in the perspectives of engineering education and the practices.

Expert background

A. *Would you please tell me about your background and working experiences in the field of sustainability in engineering education?*
B. *What do you think about education about sustainability at your university in general and in your department?*
C. *Have you lead or participated in developing a sustainability course or reform the existing course to incorporate sustainability?*

General information

A. *What is the course name?*
B. *When the course is started to offer to the students?*
C. *How many teachers are appointed for this course?*

Structuring the course

A. *Would you tell me the process taken to develop the course?*
B. *Based on the course outlines, I believed that the course was (re)designed to incorporate education about sustainability. Why do you choose to redesign the course in such way (stand-alone model or integrated model)?*

Constructing learning objectives and course contents

A. *What are your opinions on the sustainability competencies that have been structured in the learning objectives?*
B. *Based on the course outlines, I believed that the course is more focusing on (one pillar, two pillars or all three pillars are fairly balanced). Why do you choose to focus more on (one pillar, two pillars or all three pillars)?*
C. *How will this approach imply the concepts of sustainability?*

Targeting the groups

In your course, do you have specific methods of choosing your target groups (the students)?

Selecting teaching strategies

A. *What is the main teaching strategy applied in the course?*
B. *Why did you choose that particular teaching strategy?*
C. *Besides the main strategy, could you explain if there was other teaching strategy applied to the course?*

Assessment methods

A. *What are the methods have been used for assessment?*
B. *To what extent the assessments can be reflect the students´ competencies?*

Appendix B.5 Course evaluation for teacher

Effectiveness of Sustainability in Engineering Education

A PhD project (2011 – 2014)

Hello and Good Day.

My name is Mahyuddin Arsat and currently I am a PhD Fellow in Aalborg Universitet in Denmark (AAU). Previously I was a teacher in Department of Technical and Engineering Education at Faculty of Education, Universiti Teknologi Malaysia (UTM).

Generally, the study is administered to evaluate the effectiveness of learning sustainability amongst students in engineering education. The effectiveness is measured by the comparison between teacher expectations and students learning outcomes. There are five engineering courses in UTM and one engineering course in AAU selected for this PhD research. The selection was based on the course contents and students learning outcomes that related to sustainability in engineering education.

It is expected that the respondents will spend thirty minutes to answers this research instrument.

Participants:
Engineering teachers at Aalborg Universitet, Denmark
Engineering teachers at Universiti Teknologi Malaysia, Malaysia

Aim:
Measuring teacher expectations in term of students ´ knowledge, Skills and Attitudes on Sustainability in Engineering Education

Outlines:
1. An introduction to conceptual maps
2. A conceptual maps instruction
3. An introduction to procedural diagram and self-rate procedure
4. A procedural diagram instruction
5. A self-rate instruction
6. Strongly agree/Strongly disagree items

Name				
Course				
Program				
University				
Date				
Do you familiar with Conceptual Maps?	Yes		No	
Do you familiar with Procedural Diagram?	Yes		No	

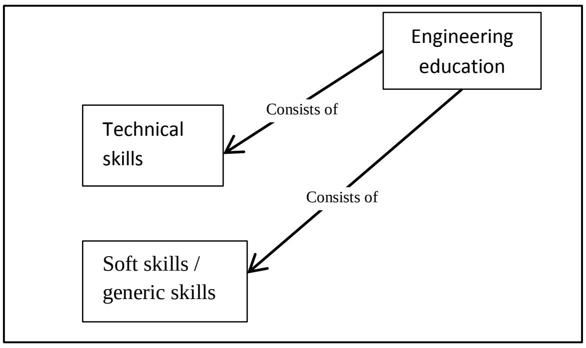
1. Introduction to Conceptual Maps.

Concept maps are graphical tools for organizing and representing knowledge. The main features of the concept maps are:

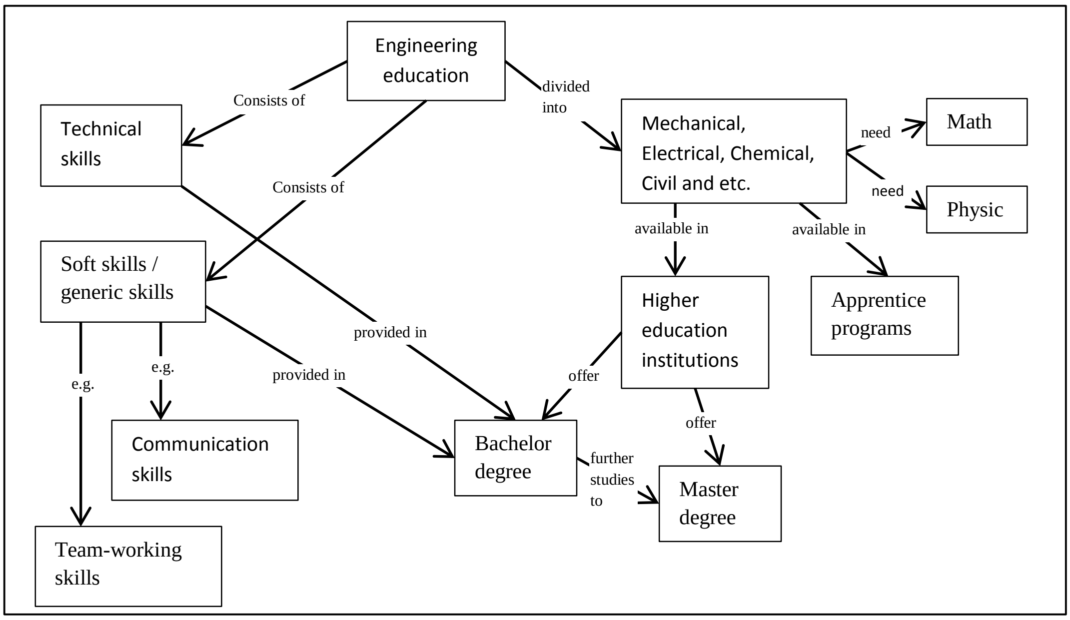
i) Concepts, which usually enclosed in circles or boxes.
ii) Connecting line, which linking between two concepts
iii) Words on the line, which referred to as linking words

For example,

A concept map always starts with a general concept, for this case *Engineering Education* is the general concept. It is in the top of the hierarchy of the concept. The more specific concepts are arranged in lower hierarchy, for this case are *Technical Skills* and *Soft skills/ General skills*. Both concepts are connected with arrows and *consist of* as the linking word.



Below is an example of the concept maps for engineering education.



2. By using conceptual maps, describe **what the expected knowledge (could obtain in your course) about sustainability should acquire by the students.** You may find the basic components for sustainability in engineering that possibly could help you to develop a concept maps.

Sustainability

Basic components for Sustainability in Engineering:

Global issues	Local issues	Holistic approach	Empowerment of engineer	Environment management	Quality in engineering
Resources	Green/Eco technology	Culture	Social rights/values	Citizenry	Equity between generations
		Economy	Stakeholders		

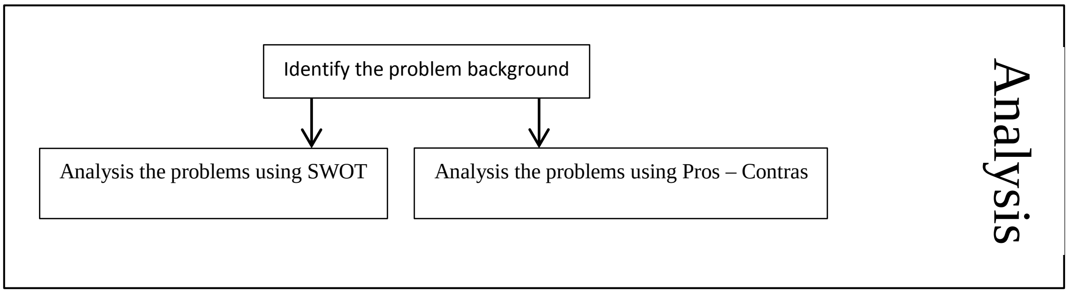
3. Introduction to procedural diagram and self-rate procedure.

Procedural diagram is graphical tool for organizing and representing a set of procedure. Usually the procedure is interpreted in skills form. The main features of the procedural diagram are:

i) Skills, which enclosed by boxes
ii) Connecting line, which linking between two skills
iii) Stages of design

For example,

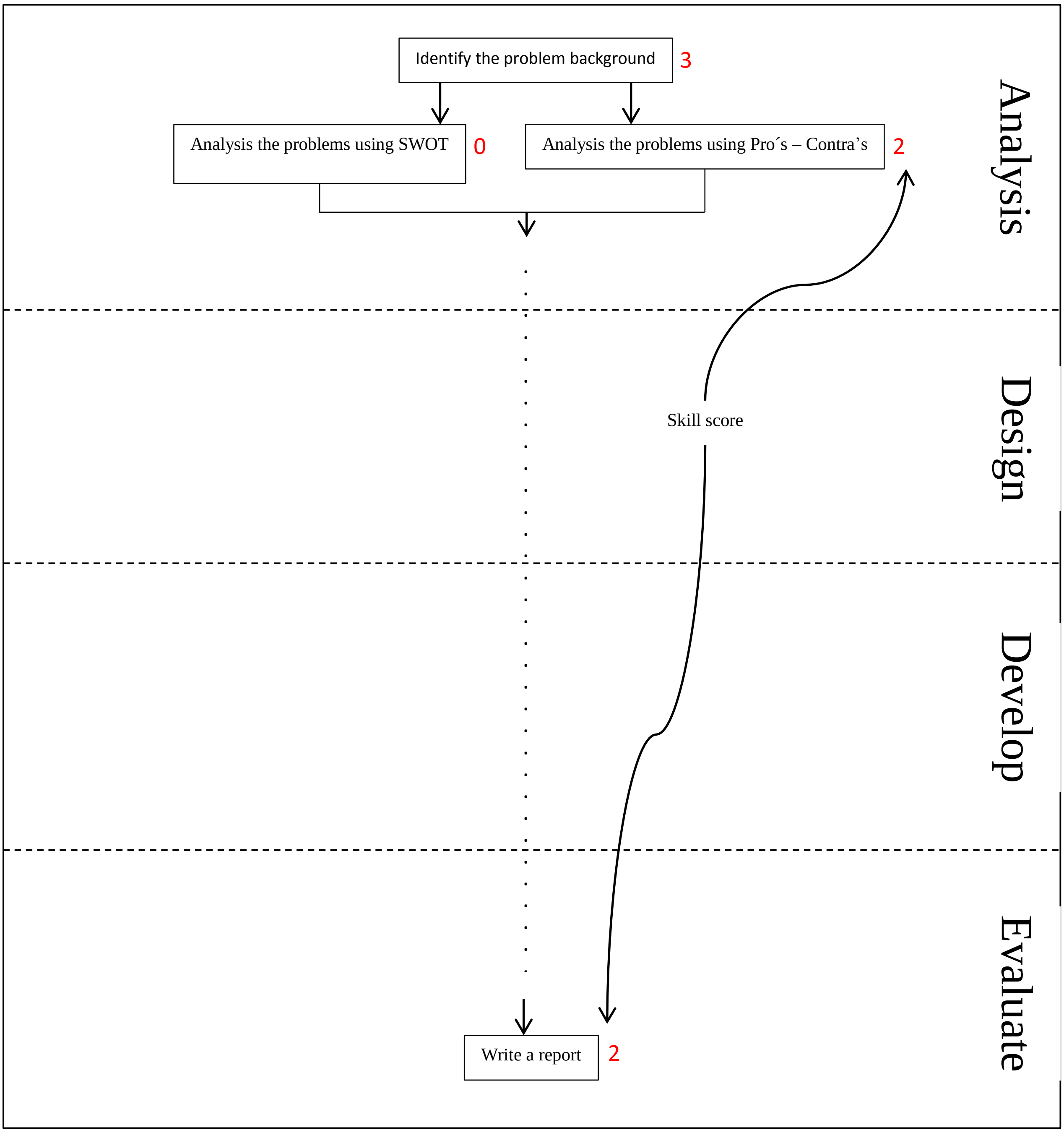
Procedural diagram consists of four stages of design, which are Analysis, Design, Develop and Evaluate stages. It is always starts with the first step at the very beginning of the design process, for this case the first step is the skill to *identify the problem background*. The next step of the process could consist of a single skill or more e.g. *Analysis the problems using SWOT* and *Analysis the problems using Pro´s – Contra´s.* Both skills are connecting with arrow. In hierarchal fashion, the top skill(s) is (are) prerequisite for the skill(s) in the below.



After the procedural diagram is completed, please rate yourself by referring to the five-point score. In order to rate the skills, each of the skill has to be rate in five-point score. The scores are:

Score	Level	Description
0	Unskilled	Do not have experience of the skill.
1	Basic	Experienced in applying the skill on simple task.
2	Skilled	Experienced in applying the skill on difficult task.
3	Master	Experienced in applying the skill on complex task.
4	Expert	Experienced in applying the skill on sophisticated task

Below is an example on how you rate your skills on the procedural diagram. The score is stated on the right side of the box. Therefore the number will indicate your skill level in that particular skill. For example, with score of three at *Identify the problem background* box indicate that you are experienced in applying the skill on complex task (Master level).



4. By using procedural diagram, describe **what the expected skills should acquire by the students (could obtain in your course) in relating to develop a sustainable technology.**

Analysis

Design

Develop

Evaluate

5. By using your procedural diagram (in question 4); rate expected score at each of the skills that you stated in.

Level	Unskilled	Basic	Skilled	Master	Expert
Score	0	1	2	3	4

6. Please indicate your opinion about each of items below by marking one of the five scales in the columns on the right side. You may choose any one of the five scales, ranging from (1) *Strongly disagree* to (5) *Strongly agree* as each represents a degree on the continuum. **Please respond to each of the items by considering your expectation on students' attitude towards engineer as a profession in the future.**

No.	Statements	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
	As engineers,					
6a.	They should have full autonomy over decision making	①	②	③	④	⑤
6b.	Ethics are important for them	①	②	③	④	⑤
6c.	Stakeholders should be part in developing their engineering solutions	①	②	③	④	⑤
6d.	Their engineering solution will meet the need of cultural diversity	①	②	③	④	⑤
6e.	They will take into consideration the needs of society/community	①	②	③	④	⑤
6f.	Their aim is to contribute to an equal distribution of wealth	①	②	③	④	⑤
6g.	They will value social equity in engineering solutions	①	②	③	④	⑤
6h.	Their engineering solution aims at reducing gaps between generations	①	②	③	④	⑤
6i.	It is important for them to protecting social rights	①	②	③	④	⑤
6j.	Their engineering solution aims to contribute to human health	①	②	③	④	⑤
6k.	Their aim is to conserve natural ecosystems	①	②	③	④	⑤
6l.	Their aim is to minimize depletion of resources	①	②	③	④	⑤
6m.	They responsible not only in the company but also outside the company	①	②	③	④	⑤
6n.	It is important for them to improve efficiency in engineering solution	①	②	③	④	⑤
6o.	They will apply environmental impact assessment tools	①	②	③	④	⑤
6p.	They agree the pollution should be compensated in monetary value	①	②	③	④	⑤
6q.	Economic development is important for them	①	②	③	④	⑤
6r.	Their engineering solution will drive the economy	①	②	③	④	⑤
6s.	They will manage the foreseen pollutions	①	②	③	④	⑤
6t.	Their aim is to eliminate all waste products	①	②	③	④	⑤

6u.	They will apply a holistic approach in decision making	① ② ③ ④ ⑤
6v.	The balance of environmental, social and economic aspects is important for them	① ② ③ ④ ⑤
6w.	They will identify potential impacts of engineering to the local	① ② ③ ④ ⑤
6x.	Local aspirations is important for them in engineering solutions	① ② ③ ④ ⑤
6y.	Global security is a part of their responsibility	① ② ③ ④ ⑤
6z.	They will take part in solving poverty.	① ② ③ ④ ⑤

Appendix B.6 Course evaluation for students

Effectiveness of Sustainability in Engineering Education

A PhD project (2011 – 2014)

Hello and Good Day.

My name is Mahyuddin Arsat and currently I am a PhD Fellow in Aalborg Universitet in Denmark (AAU). Previously I was a teacher in Department of Technical and Engineering Education at Faculty of Education, Universiti Teknologi Malaysia (UTM).

Generally, the study is administered to evaluate the effectiveness of learning sustainability amongst students in engineering education. The effectiveness is measured by the comparison between teacher expectations and students learning outcomes. There are five engineering courses in UTM and one engineering course in AAU selected for this PhD research. The selection was based on the course contents and students learning outcomes that related to sustainability in engineering education.

It is expected that the respondents will spend thirty minutes to answers this research instrument.

Participants:
Engineering students at Aalborg Universitet, Denmark
Engineering students at Universiti Teknologi Malaysia, Malaysia
Aim:
Measuring Students´ Knowledge and Skills on Sustainability in Engineering Education

Outlines:

7. An introduction to conceptual maps
8. A conceptual maps instruction
9. An introduction to procedural diagram and self-rate procedure
10. A procedural diagram instruction
11. A self-rate instruction

Name				
Course				
Program				
University				
Date				
Academic year of studies				
Please state your previous discipline(s)				
Please state your previous course(s) that related to Sustainable Development				
Do you familiar with Conceptual Maps?	Yes		No	
Do you familiar with Procedural Diagram?	Yes		No	

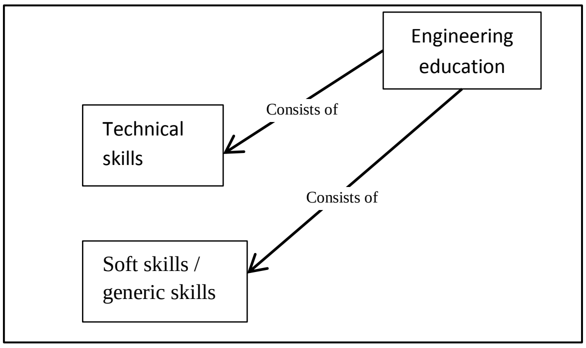
1. Introduction to Conceptual Maps.

Concept maps are graphical tools for organizing and representing knowledge. The main features of the concept maps are:

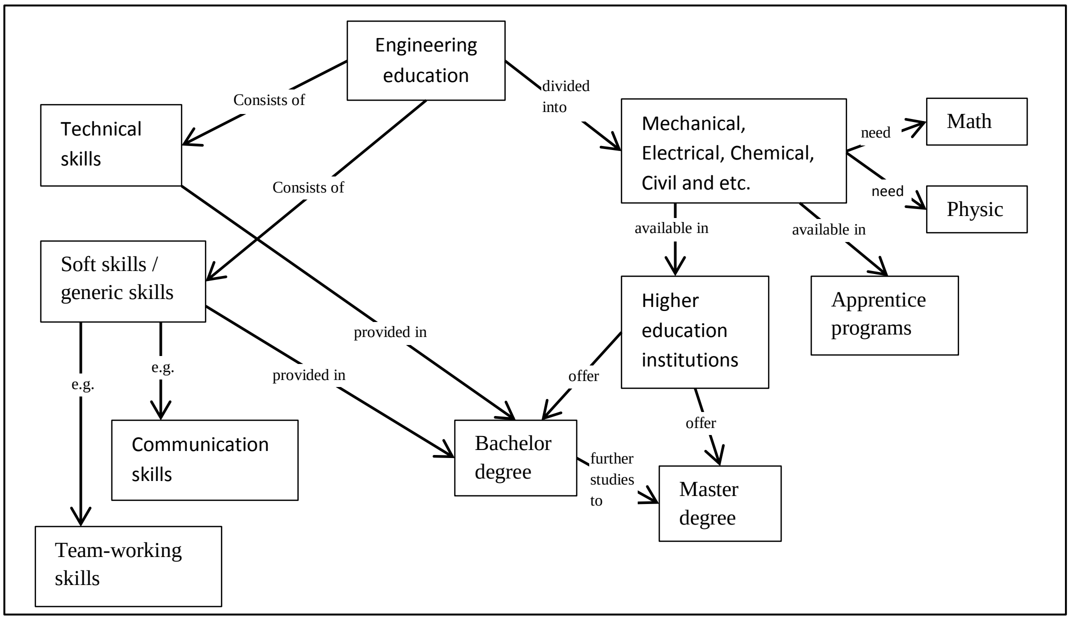
iv) Concepts, which usually enclosed in circles or boxes.
v) Connecting line, which linking between two concepts
vi) Words on the line, which referred to as linking words

For example,

A concept map always starts with a general concept, for this case *Engineering Education* is the general concept. It is in the top of the hierarchy of the concept. The more specific concepts are arranged in lower hierarchy, for this case are *Technical Skills* and *Soft skills/ General skills*. Both concepts are connected with arrows and *consist of* as the linking word.



Below is an example of the concept maps for engineering education.



2. By using conceptual maps, describe **what** you understand with a Sustainable Technology. You may find the basic components for sustainability in engineering that possibly could help you to develop a concept maps.

Sustainable technology

Basic components for Sustainability in Engineering:

Global issues	Local issues	Holistic approach	Empowerment of engineer	Environment management	Quality in engineering
Resources	Green/Eco technology	Culture	Social rights/values	Citizenry	Equity between generations
		Economy	Stakeholders		

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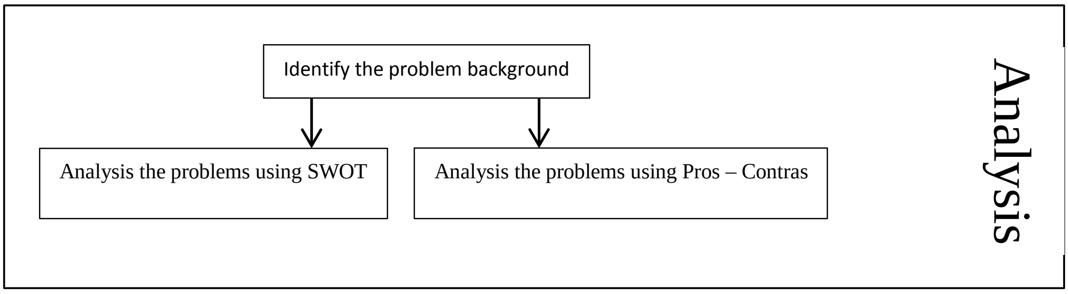

After the procedural diagram is completed, please rate yourself by referring to the five-point score. In order to rate the skills, each of the skill has to be rate in five-point score. The scores are:

Score	Level	Description
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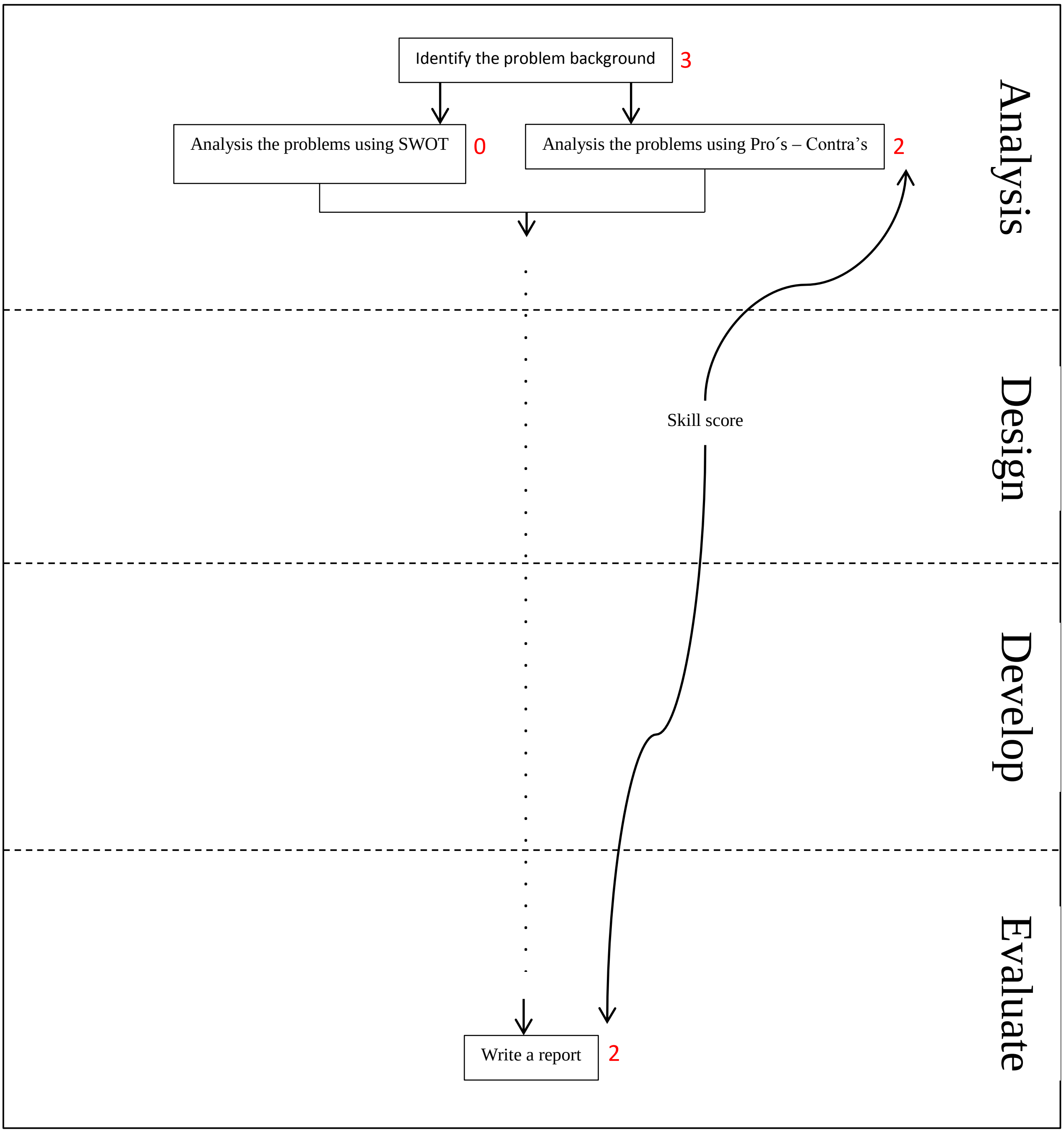
1	Basic	Experienced in applying the skill on simple task.
2	Skilled	Experienced in applying the skill on difficult task.
3	Master	Experienced in applying the skill on complex task.
4	Expert	Experienced in applying the skill on sophisticated task

Below is an example on how you rate your skills on the procedural diagram. The score is stated on the right side of the box. Therefore the number will indicate your skill level in that particular skill. For example, with score of three at *Identify the problem background* box indicate that you are experienced in applying the skill on complex task (Master level).



4. By using procedural diagram, describe **how** you develop a Sustainable Technology.

Analysis

Design

Develop

Evaluate

Write a report

5. By using your procedural diagram (in question 4); rate yourself at each of the skills that you stated in.

Level	Unskilled	Basic	Skilled	Master	Expert
Score	0	1	2	3	4

Effectiveness of Sustainability in Engineering Education

A PhD project (2011 – 2014)

Hello and Good Day.

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It is expected that the respondents will spend ten minutes to answers this research instrument.

Participants:
Engineering students at Aalborg Universitet, Denmark
Engineering students at Universiti Teknologi Malaysia, Malaysia

Aim:
Measuring Students´ Attitudes on Sustainability in Engineering Education

Name	
Course	
Program	
University	
Date	
Academic year of studies	
Please state your previous discipline(s)	
Please state your previous course(s) that related to Sustainable Development	

Please indicate your opinion about each of items below by marking one of the five scales in the columns on the right side. You may choose any one of the five scales, ranging from (1) *Strongly disagree* to (5) *Strongly* *agree* as each represents a degree on the continuum. **Please respond to each of the items by considering your current attitude towards engineer as your profession in the future.**

No.	Statements	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
	As an engineer,					
6a.	I should have full autonomy over decision making	1	2	3	4	5
6b.	Ethics are important for me	1	2	3	4	5
6c.	Stakeholders should be part in developing my engineering solutions	1	2	3	4	5
6d.	My engineering solution will meet the need of cultural diversity	1	2	3	4	5
6e.	I will take into consideration the needs of society/community	1	2	3	4	5
6f.	My aim is to contribute to an equal distribution of wealth	1	2	3	4	5
6g.	I will value social equity in engineering solutions	1	2	3	4	5
6h.	My engineering solution aims at reducing gaps between generations	1	2	3	4	5
6i.	It is important for me to protecting social rights	1	2	3	4	5
6j.	My engineering solution aims to contribute to human health	1	2	3	4	5
6k.	My aim is to conserve natural ecosystems	1	2	3	4	5
6l.	My aim is to minimize depletion of resources	1	2	3	4	5
6m.	I am responsible not only in the company but also outside the company	1	2	3	4	5
6n.	It is important for me to improve efficiency in engineering solution	1	2	3	4	5
6o.	I will apply environmental impact assessment tools	1	2	3	4	5
6p.	I agree the pollution should be compensated in monetary value	1	2	3	4	5
6q.	Economic development is important for me	1	2	3	4	5
6r.	My engineering solution will drive the economy	1	2	3	4	5
6s.	I will manage the foreseen pollutions	1	2	3	4	5
6t.	My aim is to eliminate all waste products	1	2	3	4	5
6u.	I will apply a holistic approach in decision making	1	2	3	4	5

6v.	The balance of environmental, social and economic aspects is important for me	① ② ③ ④ ⑤
6w.	I will identify potential impacts of engineering to the local	① ② ③ ④ ⑤
6x.	Local aspirations is important for me in engineering solutions	① ② ③ ④ ⑤
6y.	Global security is a part of my responsibility	① ② ③ ④ ⑤
6z.	I will take part in solving poverty.	① ② ③ ④ ⑤

Appendix B.7 Self-administered questionnaires – probing

Hello and Good Day.

My name is Mahyuddin Arsat and currently I am a PhD Fellow in Aalborg Universitet in Denmark (AAU). Previously I was a teacher in Department of Technical and Engineering Education at Faculty of Education, Universiti Teknologi Malaysia (UTM).

Generally, the study is administered to evaluate the effectiveness of learning sustainability amongst students in engineering education. The effectiveness is measured by the comparison between teacher expectations and students learning outcomes. There are five engineering courses in UTM and one engineering course in AAU selected for this PhD research. The selection was based on the course contents and students learning outcomes that related to sustainability in engineering education.

It is expected that the respondents will spend ten minutes to answers this research instrument.

Participants:
Engineering students at Aalborg Universitet, Denmark
Engineering students at Universiti Teknologi Malaysia, Malaysia

Aim:
This survey is aim to identify the factors that contribute to your learning outcomes and competencies related to Sustainability

Name	
Course	
Program	
University	
Date	
Academic year of studies	
Please state your previous discipline(s)	
Please state your previous course(s) that related to Sustainable Development	

1. Please indicate your opinion about each of items below by marking one of the five scales in the columns on the right side. You may choose any one of the five scales, ranging from (1) *Strongly disagree* to (5) *Strongly agree* as each represents a degree on the continuum. **Please respond to each of the items by considering your current perspective for this course**

No.	Statements	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
	In this course,					
a.	My teacher determined the knowledge for me to learn	①	②	③	④	⑤
b.	I participated in the lecture	①	②	③	④	⑤
c.	I participated in my group discussion	①	②	③	④	⑤
d.	I acquired the knowledge of sustainability from listening to the panels in seminar	①	②	③	④	⑤
e.	I learnt the knowledge of sustainability from my own search	①	②	③	④	⑤
f.	I learnt the knowledge of sustainability while visit several industrial companies	①	②	③	④	⑤
g.	My teacher outlined the knowledge with some flexibility for me to learn	①	②	③	④	⑤
h.	I contributed in solving a problem(s)	①	②	③	④	⑤
i.	I acquired the knowledge of sustainability from listening to the lectures	①	②	③	④	⑤
j.	I acquired the knowledge of sustainability through my group´s project	①	②	③	④	⑤
k.	I learnt the knowledge of sustainability from case studies provided	①	②	③	④	⑤
l.	I learnt the knowledge of sustainability in the classroom	①	②	③	④	⑤
m.	My teacher facilitated me in determining the knowledge I want to learn	①	②	③	④	⑤
n.	I participated in discussions with engineers in industry	①	②	③	④	⑤
o.	I participated in peer teaching	①	②	③	④	⑤
p.	I acquired the knowledge of sustainability from solving a problem(s)	①	②	③	④	⑤
q.	I acquired the knowledge of sustainability from listening to the panels in seminar	①	②	③	④	⑤
r.	I learnt the knowledge of sustainability from several people	①	②	③	④	⑤
s.	I learnt the knowledge of sustainability from materials provided in seminar	①	②	③	④	⑤
t.	I learnt the knowledge of sustainability in the workshops/laboratories	①	②	③	④	⑤

u.	I had a full liberty to determine the knowledge I want to learn	① ② ③ ④ ⑤
v.	I contributed in my group´s project	① ② ③ ④ ⑤
w.	I participated in the seminar	① ② ③ ④ ⑤
x.	I acquired the knowledge of sustainability through discussions with my friends	① ② ③ ④ ⑤
y.	I acquired the knowledge of sustainability from peer teaching	① ② ③ ④ ⑤
z.	I learnt the knowledge of sustainability from course materials	① ② ③ ④ ⑤
aa.	I learnt the knowledge of sustainability from our industrial visit reports	① ② ③ ④ ⑤
ab.	I learnt the knowledge of sustainability in our discussion room	① ② ③ ④ ⑤
ac.	I learnt the knowledge of sustainability in my own room	① ② ③ ④ ⑤

Appendix A.8 Open-ended questions

1. In a group of two, discuss with your partner on deliverability of the framework. Deliverability could be the capability of the framework to:
    ii. Present the ideas/models/etc.
    iii. Provide understanding of the ideas/models/etc.

2. Discuss with your partner on practicality of the framework. Practicality could be the capability of the framework to:
    i. Engage the teacher on the overall process
    ii. Applicable to your own engineering course

3. Discuss with your partner on any aspects that need to be highlighted for improvement of the framework.

Appendix C

Table C.1 summary of designing effective questions

Ask the right question: • *Constructs that the question measures should meet analysis objectives* • *The question to measure the construct should be one that respondents can answer* • *Answers to the question should be a measure of the chosen construct*
Ask questions that are consistently understood: • *Avoid unfamiliar and technical terms* • *Define abstract nouns and verbs* • *Avoid adjectives and adverbs* • *Use a time reference for any question that reasonably might vary over time* • *Avoid imbedded assumptions* • *Ask one question at a time (avoid multi-barreled questions)*
Ask questions that respondents can retrieve answer to: • *Respondents should have the information needed to answer the question.* • *Questions should ask about information respondents have access to.* • *Questions should ask about constructs in terms that respondents use.* • *Questions should be about respondents and not about other people (Avoid proxy questions)* • *If proxy questions must be asked, ask about factual and behavioral issues, not internal states.* • *Length of the reference period should be consistent with the significance or the event.* • *Decompose complex questions to make questions easier to answer and give respondents more time to think about the topic.* • *Provide retrieval cues to aid memory*
Ask questions for which respondents can provide appropriate response: • *Response task should be clear and obvious from the question.* • *Response options should match the questions.* • *Response options should not assume regularity.* • *For closed-ended questions, response options should be exhaustive and mutual exclusive.* • *Direct rating tasks are better than indirect ratings*

Ask questions that respondents are willing to answer accurately:
• *Minimize respondent concerns about being seen in a negative light or having their answers interpreted inaccurately.*
• *Give attention to:*
    o *Introductions*
    o *Vocabulary*
    o *Context*
    o *Response alternatives*

Fowler and Consenza (2008) pp. 159

Appendix D

Table D.1 Code of categories

Code	Category	Code	Category
C1	Environmental Management	C9	Citizenry
C2	Environmental Assessment	C10	Culture
C3	Resources	C11	Stakeholders
C4	Green/Eco Technology	C12	Empowerment of Engineer
C5	Economic	C13	Holistic / Systemic Approach
C6	Quality in Engineering	C14	Global Issues
C7	Social Rights/Values	C15	Local Issues
C8	Equity		

Appendix E

Pilot studies

The following are the list of pilot studies that have been conducted to test the research instruments.

Contents

Appendix E.1 Pilot study for research instrument phase 1

Ranking task, structured interview and semi-structured interview are the instruments used for collecting data in research phase 1. The instruments were tested at once in a pilot study that has been conducted on January 2012. There were two samples participated in this pilot study. The samples are teachers in Aalborg Universitet, Denmark and Universiti Pendidikan Sultan Idris, Malaysia.

Responses on the ranking task

Both respondents have shown that the 10 components are doable for respondents to rank. Although both respondents consumed quite some time in ranking the ten components, the approach to apply "loose-cards" on the components of sustainability helps respondent on the task.

Responses on the structured interview

Giving feedbacks on each rank are impractical; this is because during the task is carried out, the respondents gave feedbacks by thinking aloud. Most of the respondents justified their decision while thinking aloud. In the perspective of respondents, some components are perceived equally important / fairly important compare to the component at the adjacent rank. Therefore, the researcher has restructured the questions by clustering the components at rank 1 to 3 as highly important, 4 to 7 as important and 8 to 9 as less important. So that the respondents could give responses and justifications of why the components are important to learning of sustainability in engineering education, not why it has been positioned in that particular rank.

Responses on the semi structured interview

The respondents have showed that the questions that have been posed to them are well constructed and addressing the research aims to provide overview on the sustainability incorporation in engineering curricula. The follow-up questions (unstructured questions) have provided researcher to explore and understand further the sustainability incorporation in the context of the respondents.

Appendix E.2 Pilot study for research instrument phase 2

A semi structured interview is a method that has been employed for data gathering in the research phase 2. The instrument was tested on January 2012 to two samples.

In overall, the questions are constructed entirely based on the findings in research phase 1 and results from document analyses in research phase 2. Initially the questions were constructed by explicitly including the terms such as stand-alone model, integrated model, disciplinary approach, interdisciplinary approach and themes (findings from research phase 1) and the common components of curriculum design such as learning objectives, assessment methods and learning strategies. However, the pilot study showed that by employing all those terms from research phase 1 in the questions has created confusion amongst responded. This is due to the unfamiliar terms in the context of course design. In fact, most of the time the researcher had to explain further the terms to the respondents. Therefore, the terms are taken out from the questions in the final version.

The questions also improved in its sequence. The researcher has finalized the sequence of the questions based on the common components of curriculum design. So that, the interviewee can easily understands the questions and be able to response the questions in the perspective of curriculum design.

Appendix E.3 Pilot study for research instrument phase 3

Conceptual maps, Procedural diagrams, self-administered questionnaires and a probing tool are the instruments for research phase 3. These instruments have been tested all at once by 17 engineering students of UTM who have similar background to the actual samples.

Responses on the Conceptual Maps

The response rate for this instrument is 88%. 15 out of 17 students have responded the instrument as it aims to construct conceptual maps. Most of the students constructed conceptual maps by employing the provided components of sustainability and some of them used their own words to describe concepts for sustainable technology. Therefore, there is no change have been made for this instrument.

Responses on the Procedural Diagrams

The response rate for this instrument is 71%. 12 out of 17 students have responded the instrument by providing procedural diagrams. 4 of the students were misunderstanding by listing down the skills (not in diagram but in point form) and not completing the diagrams. As for improvement, the researcher has provided clearer example and explanation on how to construct procedural diagrams.

Reliability test on the construct items for self-administered questionnaires

The following tables are the results from reliability test on the instrument. According to George and Mallery (2001), the coefficient value more than 0.7 is considered reliable for internal consistency. Due to the high value of Cronbach´s Alpha (0.955) there is no further changes has been made for this instrument.

Reliability Statistics

Cronbach's Alpha	N of Items
,955	26

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
a	103,7059	153,096	,504	,956
b	103,3529	153,618	,765	,953
c	103,6471	150,868	,635	,954
d	103,5294	152,265	,719	,953
e	103,3529	154,243	,721	,953
f	103,7059	152,971	,627	,954
g	103,6471	161,368	,276	,957
h	103,7647	160,941	,251	,957
i	103,6471	153,618	,733	,953
j	103,4118	148,257	,889	,951

k	103,2941	150,096	,845	,952
l	103,4706	148,515	,809	,952
m	103,4118	152,257	,758	,953
n	103,4118	152,632	,641	,954
o	103,4118	150,632	,754	,953
p	103,6471	159,743	,173	,961
q	103,2941	151,096	,784	,952
r	103,3529	151,868	,756	,953
s	103,7647	155,316	,472	,956
t	103,5882	152,632	,741	,953
u	103,5882	151,257	,723	,953
v	103,2941	151,721	,746	,953
w	103,4706	155,515	,707	,954
x	103,3529	152,993	,810	,953
y	103,6471	150,368	,729	,953
z	103,4118	148,382	,882	,951

Reliability test on the construct items for the Probing tool

The following tables are the results from reliability test on the instrument. Due to the high value of Cronbach´s Alpha (0.928) there is no further changes has been made for this instrument.

Reliability Statistics

Cronbach's Alpha	N of Items
,928	29

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
a	106,6471	132,493	,350	,928
b	106,7059	127,971	,641	,925
c	106,5294	128,390	,791	,924
d	107,1176	126,360	,661	,924
e	107,4706	128,640	,496	,926
f	107,4118	133,132	,125	,934
g	106,9412	130,809	,427	,927
h	106,9412	131,059	,344	,928
i	106,7647	126,691	,668	,924

j	106,8824	128,235	,560	,925
k	106,8235	126,779	,612	,925
l	106,9412	125,559	,559	,926
m	106,6471	126,118	,736	,923
n	107,1765	124,654	,604	,925
o	106,7647	127,316	,750	,924
p	107,0588	126,309	,600	,925
q	107,3529	124,868	,583	,925
r	107,0588	127,809	,585	,925
s	107,4706	130,140	,471	,927
t	107,3529	131,243	,377	,928
u	107,0000	127,250	,563	,925
v	106,6471	127,493	,636	,925
w	107,1176	126,735	,636	,924
x	106,8824	126,610	,674	,924
y	107,0000	125,375	,683	,924
z	106,9412	129,934	,492	,926
aa	107,0000	131,125	,378	,928
ab	107,0588	127,184	,628	,925
ac	107,3529	127,743	,394	,929

Appendix F

Descriptive analysis of respondents´ feedbacks

The following are the list of analyses that have been carried out in research phase 3.

Contents

Appendix F.1 Descriptive analysis for Case A

Table F.1

		My teacher determined the knowledge for me to learn	My teacher outlined the knowledge with some flexibility for me to learn	My teacher facilitated me in determining the knowledge I want to learn	I had a full liberty to determine the knowledge I want to learn
N	Valid	16	16	16	16
	Missing	0	0	0	0
Mean		4.19	4.13	3.69	3.81
Std. Error of Mean		0.14	0.18	0.15	0.21
Std. Deviation		0.54	0.72	0.60	0.83

Table F.2

		I participated in the lecture	I participated in my group discussion	I contributed in my group´s project	I contributed in solving problem (s)	I participated in the seminar	I participated in discussion with engineers in industry	I participated in peer teaching
N	Valid	16	16	16	16	16	16	16
	Missing	0	0	0	0	0	0	0
Mean		4.00	4.19	4.38	3.94	4.06	2.94	4.19
Std. Error of Mean		0.13	0.16	0.15	0.14	0.14	0.21	0.19
Std. Deviation		0.52	0.66	0.62	0.57	0.57	0.85	0.75

Table F.3

		I acquired the knowledge of sustainability from listening to the lecture	I acquired the knowledge of sustainability through my group´s project	I acquired the knowledge of sustainability from solving a problem (s)	I acquired the knowledge of sustainability through discussions with engineers in industry	I acquired the knowledge of sustainability through discussion with my friends	I acquired the knowledge of sustainability from peer teaching	I acquired the knowledge of sustainability from listening to the panels in seminar
N	Valid	16	16	16	16	16	16	16
	Missing	0	0	0	0	0	0	0
Mean		4.19	4.13	3.75	3.81	3.88	3.88	3.81
Std. Error of Mean		0.16	0.15	0.25	0.19	0.13	0.15	0.23
Std. Deviation		0.66	0.62	1.00	0.75	0.50	0.62	0.91

Table F.4

		I learnt the knowledge of sustainability from course materials	I learnt the knowledge of sustainability from our industrial visit reports	I learnt the knowledge of sustainability from case studies provided	I learnt the knowledge of sustainability from several people	I learnt the knowledge of sustainability from my own search	I learnt the knowledge of sustainability from materials provided in seminar
N	Valid	16	16	16	16	16	16
	Missing	0	0	0	0	0	0
Mean		3.69	3.38	3.88	3.81	3.13	3.81
Std. Error of Mean		0.12	0.27	0.15	0.16	0.20	0.19
Std. Deviation		0.48	1.09	0.62	0.66	0.81	0.75

Table F.5

		I learnt the knowledge of sustainability in the classroom	I learnt the knowledge of sustainability in the workshops/laboratories	I learnt the knowledge of sustainability in our discussion room	I learnt the knowledge of sustainability in my own room	I learnt the knowledge of sustainability while visit several industrial companies
N	Valid	16	16	16	16	16
	Missing	0	0	0	0	0
Mean		4,0000	3,4375	3,4375	3,2500	3,4375
Std. Error of Mean		,12910	,15729	,24098	,28137	,22302
Std. Deviation		,51640	,62915	,96393	1,12546	,89209

Appendix F.2 Descriptive analysis for Case B

Table F.6

		My teacher determined the knowledge for me to learn	My teacher outlined the knowledge with some flexibility for me to learn	My teacher facilitated me in determining the knowledge I want to learn	I had a full liberty to determine the knowledge I want to learn
N	Valid	23	23	23	23
	Missing	0	0	0	0
Mean		4,0435	3,6522	3,8261	3,5217
Std. Error of Mean		,14715	,16162	,13560	,15232
Std. Deviation		,70571	,77511	,65033	,73048

Table F.7

		I participated in the lecture	I participated in my group discussion	I contributed in my group´s project	I contributed in solving problem (s)	I participated in the seminar	I participated in discussion with engineers in industry	I participated in peer teaching
N	Valid	23	23	23	23	23	23	23
	Missing	0	0	0	0	0	0	0
Mean		3,5652	4,2609	4,0435	3,5652	3,6087	3,5217	3,5652
Std. Error of Mean		,15175	,12911	,17193	,17588	,17490	,18724	,17588
Std. Deviation		,72777	,61919	,82453	,84348	,83878	,89796	,84348

Table F.8

		I acquired the knowledge of sustainability from listening to the lecture	I acquired the knowledge of sustainability through my group´s project	I acquired the knowledge of sustainability from solving a problem (s)	I acquired the knowledge of sustainability through discussions with engineers in industry	I acquired the knowledge of sustainability through discussion with my friends	I acquired the knowledge of sustainability from peer teaching	I acquired the knowledge of sustainability from listening to the panels in seminar
N	Valid	23	23	23	23	23	23	23
	Missing	0	0	0	0	0	0	0
Mean		3,7391	3,9130	3,6087	3,4348	3,9565	3,5652	3,6087
Std. Error of Mean		,15676	,15288	,16321	,18678	,13304	,13811	,16321

Std. Deviation	,75181	,73318	,78272	,89575	,63806	,66237	,78272

Table F.9

		I learnt the knowledge of sustainability from course materials	I learnt the knowledge of sustainability from our industrial visit reports	I learnt the knowledge of sustainability from case studies provided	I learnt the knowledge of sustainability from several people	I learnt the knowledge of sustainability from my own search	I learnt the knowledge of sustainability from materials provided in seminar
N	Valid	23	23	23	23	23	23
	Missing	0	0	0	0	0	0
Mean		3,9130	3,6522	3,6957	3,8696	3,6957	3,2609
Std. Error of Mean		,13935	,14889	,17142	,18117	,15948	,18022
Std. Deviation		,66831	,71406	,82212	,86887	,76484	,86431

Table F.10

		I learnt the knowledge of sustainability in the classroom	I learnt the knowledge of sustainability in the workshops/laboratories	I learnt the knowledge of sustainability in our discussion room	I learnt the knowledge of sustainability in my own room	I learnt the knowledge of sustainability while visit several industrial companies
N	Valid	23	23	23	23	23
	Missing	0	0	0	0	0
Mean		3,4783	3,2174	3,6522	3,6957	3,6087
Std. Error of Mean		,16478	,18815	,17342	,15948	,19620
Std. Deviation		,79026	,90235	,83168	,76484	,94094

Appendix F.3 Descriptive analysis for Case C

Table F.11

		My teacher determined the knowledge for me to learn	My teacher outlined the knowledge with some flexibility for me to learn	My teacher facilitated me in determining the knowledge I want to learn	I had a full liberty to determine the knowledge I want to learn
N	Valid	20	20	20	20
	Missing	0	0	0	0
Mean		4,0500	4,3500	4,3000	4,1000
Std. Error of Mean		,19835	,13129	,12773	,19057
Std. Deviation		,88704	,58714	,57124	,85224

Table F.12

		I participated in the lecture	I participated in my group discussion	I contributed in my group´s project	I contributed in solving problem (s)	I participated in the seminar	I participated in discussion with engineers in industry	I participated in peer teaching
N	Valid	20	20	20	20	20	20	20
	Missing	0	0	0	0	0	0	0
Mean		4,3000	4,5500	4,4500	4,4000	3,4500	3,3000	4,2000
Std. Error of Mean		,16384	,13524	,13524	,13377	,22331	,26258	,18638
Std. Deviation		,73270	,60481	,60481	,59824	,99868	1,17429	,83351

Table F.13

		I acquired the knowledge of sustainability from listening to the lecture	I acquired the knowledge of sustainability through my group´s project	I acquired the knowledge of sustainability from solving a problem (s)	I acquired the knowledge of sustainability through discussions with engineers in industry	I acquired the knowledge of sustainability through discussion with my friends	I acquired the knowledge of sustainability from peer teaching	I acquired the knowledge of sustainability from listening to the panels in seminar
N	Valid	20	20	20	20	20	20	20
	Missing	0	0	0	0	0	0	0
Mean		4,1000	4,3500	4,2500	3,5500	4,2500	4,1000	3,7000
Std. Error of Mean		,12354	,10942	,12301	,19835	,12301	,17622	,21885

Std. Deviation	,55251	,48936	,55012	,88704	,55012	,78807	,97872

Table F.14

		I learnt the knowledge of sustainability from course materials	I learnt the knowledge of sustainability from our industrial visit reports	I learnt the knowledge of sustainability from case studies provided	I learnt the knowledge of sustainability from several people	I learnt the knowledge of sustainability from my own search	I learnt the knowledge of sustainability from materials provided in seminar
N	Valid	20	20	20	20	20	20
	Missing	0	0	0	0	0	0
Mean		4,2500	3,9000	4,2000	3,8500	3,7000	3,9500
Std. Error of Mean		,14281	,20391	,13765	,20869	,21885	,19835
Std. Deviation		,63867	,91191	,61559	,93330	,97872	,88704

Table F.15

		I learnt the knowledge of sustainability in the classroom	I learnt the knowledge of sustainability in the workshops/laboratories	I learnt the knowledge of sustainability in our discussion room	I learnt the knowledge of sustainability in my own room	I learnt the knowledge of sustainability while visit several industrial companies
N	Valid	20	20	20	20	20
	Missing	0	0	0	0	0
Mean		3,9500	3,8000	3,9500	3,9000	3,6500
Std. Error of Mean		,18460	,20000	,21120	,17622	,19568
Std. Deviation		,82558	,89443	,94451	,78807	,87509

Appendix G

Excerpt of expert´s interview

The following are the list for excerpt of expert´s interview. The interviews were conducted for research phase 1 and research phase 2.

Contents

Appendix G.1 Expert 1 – Malaysia

Name	Dr Khairulzan bin Yahya
Background	Construction Management
Institution	Universiti Teknologi Malaysia
Department/CoE	Construction Technology and Management Centre (CTMC)
Country	Malaysia
Date of interview session	April 2012

Ranking tasks:

1	Engineering ethics	6	Engineering quality
2	The fundamental concepts of sustainability	7	Economic aspect
3	Environmental management	8	Stakeholders
4	Environmental assessments	9	Local issues
5	Resources and eco-systems	10	Global issues

Feedbacks on ranking task:

- Engineering ethics provide understanding on the concept of sustainability towards the role of engineer.
- Both knowledge on environmental management and assessments are important. It is because of the methods and tools that have been introduced are related to the concept of sustainability.
- We as a consumer have giving impact on the use of resources and eco-systems.
- Generally the solutions for local solution will contribute into a global level.

Sustainability incorporation in engineering education

- Establishment of research groups: The researches are focus on noise pollution and reusable materials.
- Offer an elective course for civil engineering students, Sustainability and Environmental in Construction.
- Conducting an Environmental Week. This kind of campaign is aim to provide awareness amongst civil engineering students on the importance of environmental aspect in civil engineering.

Appendix G.2 Expert 2 – Malaysia

<table>
<tr><td rowspan="6"></td><td>Name</td><td>Associate Prof, Ir. Dr. Sharifah Rafidah Bt Wan Alwi</td></tr>
<tr><td>Background</td><td>Director of Process Systems Engineering Centre (PROSPECT) of Universiti Teknologi Malaysia (UTM). She is also a certified Energy Manager trainer and an Energy Professional under Green Technology Malaysia (GTM), as well as a Registered Electrical Energy Manager under Malaysia Energy Commissioner. Sharifah has been extensively involved in 20 research projects, 16 industrial based projects for various companies and government agencies and has trained engineers from more than 100 companies in the field of energy and water minimization. She specializes in process systems engineering with emphasis on resource conservation.</td></tr>
<tr><td>Institution</td><td>Universiti Teknologi Malaysia</td></tr>
<tr><td>Department/CoE</td><td>Process Systems Engineering Centre (PROSPECT) – Sustainability Research Alliance</td></tr>
<tr><td>Country</td><td>Malaysia</td></tr>
<tr><td>Date of interview session</td><td>April 2012</td></tr>
<tr><td colspan="3">Ranking tasks:</td></tr>
</table>

1	Stakeholders	6	Environmental assessments
2	Engineering quality	7	The fundamental concept of sustainability
3	Economic aspect	8	Engineering ethics
4	Resources and eco-systems	9	Local issues
5	Environmental management	10	Global issues

Feedbacks on ranking task:

- The knowledge of sustainability concepts have to be developed along the way of designing products.
- Throughout engineering design you have to have ethics. Of course engineering ethics are important, but when you design a product, you have to consider customer needs. In this process of developing products, then you have to make sure safety is there, and everything is there and there are no adverse effects on customer.
- Before we can assess environment, we have to have knowledge of environmental management.
- We assess the design of product, and then we find an alternative to minimize resources, and minimize the impact to environment.
- You have to design based on what customer want. In chemical engineering, our customer can be industries, government, schools and other kind of organizations.
- Normally, we want very high quality of products. We try to achieve 90% - 99% of efficiency. Then we will try to optimize resources.
- It sounds more like research. For example, I am a chemical engineering student; I will focus on my main job. Engineering solutions for local and global problems are in RnD part. So of course, when I had a lot of projects for local stakeholders, then I will find solutions for engineering problems in the local aspect.
- But then if I work on project for global stakeholders, then I will find solutions for global aspect. But

you have to prioritize the current stakeholders.
Sustainability incorporation in engineering education
- We are teaching all our graduates on sustainability. Actually, sustainability is not only applied in industries but should be started in life style.   - I think, in terms of education about sustainability in UTM is enough. But how do we really apply to real life.   - Support from top management is very important. For example, some people want to recycle but there are no facilities to recycle.   - Every year the involved lecturers will sit together to select the best project proposal, so that we could develop the scenario, and plan ahead for example the selection of industries, theme of campaign and etc. It is a very comprehensive discussion to develop the scenario for PBL.   - Theories that we used to develop our curriculum is the project should be knowledge centred, learner centred, instructional centred and all this involved communities. From there we will try to provide learning environment. So what we did, we employed PBL. We make sure that the students go through the whole process of PBL in 14 weeks.   - First, we gave them scenario, problems that they have to solve. Asked them to identify problems.   - Ask them to apply at hostel environment, in their daily life. Present to their friends and communities. We want them to have some reflections.   - When they visit plans, they have to make some reflections.   - We integrate sustainability in students projects   - For example, to develop a process flow for water balance. We tailored the project to cater sustainability.   - In introduction to engineering, we combine all three pillars of sustainability.   - In process design, we develop a project, in that case sustainability is embedded as a part of the requirements. And depended to the Major outcomes of the course. If the major outcomes are more on to environmental aspect, so the sustainability issues will be more focus on environmental aspect.   - We have another kind of strategies. Students have to conduct interviews with engineers. They have to find out what is the importance of sustainability.   - Plan visits, we ask students to prepare a set of questionnaire, visit reports and reflections.   - Our assessment methods are by the reports writing and presentations. They have to do presentations.   - We also use e-learning, we use e-learning a lot especially when students have problems on sustainability subject. They will discuss with their friends and lectures on e-learning. So it is very active.   - We gave comments and assessed. We assess based on the quality of the responses.   - We want students asking questions and responding with a point. And their friends also will add up with something else.   - We give students articles, they have to read it and to peer teach in the team.   - We also collect meeting minutes for each discussion session.   - We also have weekly seminar, we invite engineers for industries to give talks.   - The selected students' project will be involved in a water campaign that is open for whole UTM staffs and students.   - In the water campaign, we held a competition based on the students project. The projects were evaluated by engineers from industries such as Shell.

Appendix G.3 Expert 3 – Malaysia

Name	Dr. Hashim B. Hassan
Background	His areas of specialization involve polymer membrane synthesis and evaporation membrane technology. He is currently a lecturer at the Department of Chemical Engineering. He is also a member of the Separation Group of Chemical Engineering Department
Institution	Universiti Teknologi Malaysia
Department	Chemical engineering
Country	Malaysia
Date of interview session	April 2012

Ranking tasks:

1	Stakeholders	6	Local issues
2	The fundamental concept of sustainability	7	Economic aspect
3	Environmental management	8	Engineering quality
4	Environmental assessments	9	Engineering ethics
5	Global issues	10	Resources and eco-systems

Feedbacks on ranking task:

- Stakeholders are very important aspect that we should consider. It consists of industries, companies, parents, and public. Therefore, we have to satisfy their needs.
- If we want to learn about a particular knowledge, we must have the fundamental theories and concepts. We have to know the definition of sustainability, and the semantic terms. So later, it will be easier for students to understand on other aspect of sustainability such as environmental aspect.
- We have to know how to manage the environment first, and then we could identify the techniques for environmental assessments.
- We have to see the condition of the global issues, and then we can look to local issues. Therefore we could know what we should do.
- We should identify a method that usable by everyone. If we focus only on local issues, we don't know whether it is the best method.
- Generally, it is considered useless by solely focus on economical aspect if it gives negative impacts for longer period or damages the environment.

Sustainability incorporation in engineering education

- There are several courses that incorporated components of sustainability for example Introduction to Engineering. In this course, students are working in team on thematic projects. The themes are related to the concept or issues on sustainability.
- The course is offered to chemical engineering students only.
- In UTM, the awareness to incorporate sustainability in engineering curricula has been there for long time, but it just implemented recently in five years ago. UTM has highlighted Sustainability is the important aspect in engineering education. It can be seen through green campus campaign, green office and etc.
- The Introduction to Engineering course distributed the assessment tasks into 25% of test and 40% of PBL. Every week we will assess through presentations, progress reports, e-learning.

- In e-learning, students have to create topics for discussions.
- Students are also providing reflections in every two weeks on their learning, learning experiences, and issues for improvement.
- In PBL, it is consist of problem identification, peer teaching, peer teaching notes, progress reports, presentations and final report.
- The students are given by assignments that addressing question of what is engineering, what are the branches of engineering and engineering ethics. They will conduct interview sessions with engineers and gathering information of engineering profession.
- This is an active learning course. At the end of course, we will held a competition based on the project. The students will exhibit their final products and present the product for evaluation.
- Students are excited and enjoyed because they contributed to the projects and it is based on real problems.
- In this course, I employed a traditional method (chalk and talk) to deliver basic knowledge and PBL as a method for topics that involving problem solving.
- For me, lecturing method is needed to explain a new theory and it considered suitable method and easy way for explanation.
- In PBL, assessment will be conducted every week. In a peer assessment, student will assess within the group. Through peer assessment, we will know the progression for each student in the group.
- I never set a limitation when it comes to reflection. Therefore, students have liberty to write anything related to them as part of reflection tasks.

Appendix G.4 Expert 4 – Malaysia

Name	Associate Prof, Dr. Khalida Binti Muda
Background	Dr Khalida is actively involved in research under the WATER Research Alliances; UTM with strong research interest in the field of water and wastewater treatment particularly in biodegradation processes using Biogranulation Technology. She also has specialties in Environmental Management, Water Quality Analysis and Environmental Microbiology.
Institution	Universiti Teknologi Malaysia
Department	Environmental Engineering
Country	Malaysia
Date of interview session	April 2012

Ranking tasks:

1	Engineering ethics	6	Local issues
2	The fundamental concept of sustainability	7	Resources and eco-systems
3	Environmental management	8	Engineering quality
4	Environmental assessments	9	Economic aspect
5	Global issues	10	Stakeholders

Feedbacks on ranking task:

- Engineering ethics are the most important for all disciplines. If you have ethics you will follow the right way in handling things, teaching somebody and in giving a decision.
- A fundamental concept of sustainability is like a thinking system.
- The knowledge of environmental management provides the way to manage environment effectively. In the case of construction engineering, the activities such as land clearance and structuring a building effect on the environment.
- Global issues are considered more important to local issues. An issue such as global warming is needed for us to take part of it. Its effect on us and we contribute to the global warming.
- If you don't understand the concept of sustainability, you will deplete the resources and the eco-systems will be different as what we having now.
- After we preserve our resources and eco-systems, then we can talk about quality.
- We can gain economic value or gain profits in a sustainable way.
- Most stakeholders only thinking what they want, which most of it giving impact on the environment.

Sustainability incorporation in engineering education

- Learning of sustainability is throughout the civil engineering curricula.
- We discussed on what are the causes of pollution and the impacts on the important environmental components such as water, air and soil.
- Currently, I am a teacher for environmental management course.
- It offered for civil engineering students.
- We focused on water treatment
- We raised their awareness on the concept of sustainability and the impacts of civil engineering activities on the aspect of environmental.

- We relate the knowledge of sustainability with their role as an engineer.
- Students were asked to make presentations on certain topic of the course. They were worked in team. And each student participated in the presentation.
- At the end of semester, several case studies were used for EIA topic. In the final examination, students were asked to response based on the case studies.

Appendix G.5 Expert 5 – Malaysia

Name	Dr Rozana Zakaria
Background	Construction Management
Institution	Universiti Teknologi Malaysia
Department	Construction Technology and Management Centre (CTMC)
Country	Malaysia
Date of interview session	April 2012

Ranking tasks:

1	The fundamental concept of sustainability	6	Environmental assessments
2	Resources and eco-systems	7	Engineering ethics
3	Global issues	8	Economic aspect
4	Local issues	9	Engineering quality
5	Environmental management	10	Stakeholders

Feedbacks on ranking task:

- Students have to know the fundamental concept of sustainability in order to appreciate and apply sustainability in engineering.
- Ethic of engineers has not mentioned that engineer have to pay their decision to environment, however, as the engineer get the knowledge of sustainable education, they should consider the implication of their decision on environmental aspect.
- If we look at the basic concept of sustainability, the concept focus on first on economic aspect, second is social aspect and third is environmental aspect. I think it is a common practice by human. We fulfil our basic needs, shelter, financial, so what is next? We focus on quality of living and environment.
- In the case of developed countries, they maybe advanced 20 to 30 years than us but our economy is stable. Even though, our country not yet developed, we have to implement the concept of sustainability or otherwise, our conditions are getting worst.
- We have to go back to the reason why we have sustainability concept. Now we are facing global problems on resources depletion, very serious problems on pollution. Those affect our eco-systems. If we remain keep our life style as what we practices, we require more resources in the future which our globe not able to provide. For example, unrenewable materials, we keep utilized or we used continuously because of industrialization. These cause the depletion of resources and damaging the eco-systems.
- For me, sustainability is not about quality, sustainability is focus on environmental cautious.
- We have to appreciate global issues before local issues. If we don't, we couldn't appreciate local issues. For example, climate change, global warming, head island phenomenon that leads to forest wild-fire, from these issues we could connect to the local problems.

Sustainability incorporation in engineering education

- I created a new course which replacement of old course, environmental engineering.
- I want this solid course is offer to all undergraduate students, like a core subject. When it apply for master students, it is too late. Not all undergraduate students continue their study for master.
- We do not teach fundamental concept of sustainability for master student, because master is advanced study. So we only teach about application.

- In incorporating sustainability, it is not really complicated issues. We already know that they are going to be a construction manager because the program is master in construction management. So we already know the program outcomes, we have to align the course learning objectives to program learning outcomes.
- We also considered the characteristics of construction management such as wise decision making, control of construction waste. We are no longer testing them with CO2 footprint or something general.
- For undergraduate students, we teach them the fundamental concepts of sustainability not to the application level such as sustainable design, sustainable materials, and sustainable construction because we know they are going to be engineers.
- I don't think sustainability is difficult to learn. It involves global issues, environmental issues; the issues can be easily to understand.
- My main strategy is to motivate student to browse more on what is happen in real world.
- Students have to write technical papers. Based on themes, students prepared abstracts, and submit a full paper to the teacher after three times of revisions. Each week, the teacher will assess students' commitment. Students have to revise their paper up to conference paper standard.
- Site visit, taking two building that practiced energy efficiency building, green building. Students went to the site that implemented project industrial building system. So students will decide the sites.
- Students were organized living weeks and civil engineers. It is platform to explain how engineers could contribute to sustainable living. So students made exhibitions, poster presentations, and attracted undergraduate students to participate in the presentations. So student have to be creative to make the attractions. It was a group project.
- Teacher provided themes for poster presentations, the themes are:
    - Carbon emission
    - Sustainable wall
    - Sustainable roof system
    - Carbon footprint
    - Embodied energy
    - Sustainable development
- Students conducted series of talks at several technical schools and polytechnics. To explain what is sustainable development.
- Students developed questionnaires as a feedback of the talk
- Students prepared reports which included the process of preparation, literature and implementation of school visits.

Appendix G.6 Expert 6 – Malaysia

Name	Associate Prof, Dr Abdul Rahman bin Abdul Rahim
Background	Manufacturing system engineering
Institution	Universiti Teknolog Malaysia
Department	Manufacturing and industrial
Country	Malaysia
Date of interview session	May 2012

Ranking tasks:

1	Global issues	6	Engineering ethics
2	The fundamental concept of sustainability	7	Local issues
3	Resources and eco-systems	8	Engineering quality
4	Environmental assessments	9	Stakeholders
5	Environmental management	10	Economic aspect

Feedbacks on ranking task:

- Knowledge of engineering can be applied as solutions for most global issues. By understanding the global issues, students can use whole of engineering ideas to solve problems.
- We have to change systems thinking of new generation of students. Everyone concern on environmental aspect rather than thinking solely on the economic aspect.
- Understanding on the concept of sustainability is very important. Everything will start from concepts.
- For me engineering ethics are very general, it is not only on environmental aspect.
- When you talking about sustainability environmental assessments, it means whenever it related to proves or product, engineers can assess the impact on environment.
- If we deal local problems over global problems, we couldn’t see holistic view of the problems.

Sustainability incorporation in engineering education

- For my perspective, mechanical engineering is very much focus on cost-benefit. Sustainability is not included in the curricula.
- If the subject is developed by employing stand-alone model, there were no continuity in terms of contents, and students had difficulties to relate the concept with their engineering field.
- We have offered one course entitled Design for Manufacture, Design for Assembly. However this course is focusing on how to find the cost effective and the easiest way to manufacture the products. The shortest possible time and least cost.
- The incorporation of sustainability in an engineering course is highly depended on the teacher, if the teacher has high motivation and awareness on sustainability, they will incorporate the knowledge by their own initiatives.
- I think, sustainability needs to be embedded in all courses. So each course has a portion for the learning about sustainability.
- We have to sustain the existing curricula and at the same time incorporate sustainability.
- I think it will be more effective if the each component of sustainability is integrated in engineering courses. Therefore the concept of sustainability can be relevant.
- Each course is needed to be embedded with sustainability components so that students are able to apply the concept on that particular area of discipline.

Appendix G.7 Expert 7 – Malaysia

	Name	Associate Prof, Dr. Norhazilan Bin Md. Noor
	Background	- Reliability Engineering - Pipeline Integrity Assessment - Risk Assessment and Hazard Identification - Soil-Corrosion Engineering - Microbiological-Induced Corrosion - Risk-based Inspection, Repair and Maintenance
	Institution	Univesiti Teknologi Malaysia
	Department	Structure and Material
	Country	Malaysia
	Date of interview session	May 2012

Ranking tasks:

1	The fundamental concept of sustainability	6	Global issues
2	Environmental assessments	7	Engineering quality
3	Environmental management	8	Resources and eco-systems
4	Engineering ethics	9	Economic aspect
5	Local issues	10	Stakeholders

Feedbacks on ranking task:

- For me engineering ethics have been built-in amongst students. Once they are accepted as university students, they must be an ethical person.
- The stands of point of stakeholders are usually changed. Therefore their criteria always change and adaptable.
- We have to start finding solution for local issues. Issues that highly related to us and we can understand the concept and could apply to solve local issues.
- Students are more appreciate solving problems that connect to them compare to the issues that happen on other countries.
- As they familiar with the concept and local issues, then we introduce them with global issues.
- For me, after we solved problems with certain aspect of quality, then we can focus on the aspect of resources, eco-systems and economic.

Sustainability incorporation in engineering education

- Offshore structure is an elective course.
- Offered to the final year students.
- It is a course that integrates sustainability. This course is about fabricate, transport, install offshore structure and pipelines. Students will learn each segment. It integrates sustainability principles such as in pipeline installment, we learn about risk based assessments. How to assess risk, and what is the importance of assessing the risk.
- This is due to the integration of sustainability concept in oil and gas companies in Malaysia. Since 2000, Petronas and DNV biotask integrated sustainability.
- The integration is made to fit the market requirement, and sustainability as a philosophy.
- I did combine all three pillars in my course but it was not explicit.
- Even though I stressed only on economic pillars in my notes, by I combine all three pillars when it

comes to explanations. Therefore, the students do not see economic pillar is the only aspect in sustainability but combination of all pillars.

- In the process of developing this course, I identified the focus of the course, job market requirements, and integrated sustainability as a philosophy not as a subtopic, but integrated to all topics.
- I used a lot of case studies, engineering experiences and notes for the content.
- Case studies are real things and proven, therefore students are appreciated more.
- I used case studies as a method. I used case studies to connect each topic of the course, and discuss it with students.
- Deep water competition. This competition has been held from course level to national level. Students have to use bottles, straws and tins to build a floating structure. If they want to build a structure that is strong, they have to "buy" more materials to add with 2 million materials….
- This competition is a part of the assessments. It is mandatory for all students to participate and students from other classes need to apply for participation. This competition had sponsorship from Shell, MMSE and they recognized the competition.
- Normally, individual assignment is a page of essay.
- For group assignment, usually I will give a topic that they never learn in class. They have to make presentations amongst them in a small group. Therefore the students are learning from their own initiative, and explain to their friends.

Appendix G.8 Expert 8 – Malaysia

Name	Associate Prof, Dr. Muhamad Zameri Bin Mat Saman
Background	Current research interest is sustainable membrane-based manufacturing
Institution	Universiti Teknologi Malaysia
Department	Manufacturing and Industrial Engineering
Country	Malaysia
Date of interview session	May 2011

Ranking tasks:

1	Resources and eco-systems	6	Engineering quality
2	Global issues	7	Economic aspect
3	Environmental management	8	Stakeholders
4	Environmental assessments	9	Local issues
5	The fundamental concept of sustainability	10	Engineering ethics

Feedbacks on ranking task:

- We need to “open” students´ mind by explaining the importance of sustainability concepts. Explain concepts such as link manufacturing, Kanban, Kaizen, GIT concept and its relation to the successful of Japanese companies. Describe to students what is happen nowadays.
- It related to environmental aspect. For example, life cycle assessments ISO 1040 which originally ISO 14000. It is a form of environmental management. So we assess the environment after we manage them.
- When we are at the state of sustainability, therefor we can continue with quality, economic, and we can fulfill the stakeholder´s needs.
- Later, we solve local problems.
- Engineering ethics not only on sustainability issues but on all aspect of engineering. If we could provide platforms for students to understand, eventually their attitude will be more ethical.

Sustainability incorporation in engineering education

- There are two courses about sustainability for undergraduate. Both are incorporating sustainability into the existing curricula.
    - Product design
    - Design for manufacture and assembly
- A crash course on Sustainable issues was offered to students since 2009. A day course to provide fundamental knowledge on sustainability. This course is mandatory for all mechanical engineering students.
- For both course, sustainability knowledge is delivered to provide concepts of sustainability and to raise awareness.
- It is very difficult to develop a stand-alone course for mechanical engineering because it is already over-crowded.
- I think, it is enough by increase the awareness of students on sustainability, the rest, students can explore by themselves.
- I provided students with case studies in manufacturing. I used videos for example the companies that manufacture vacuum cleaner. So that the students gave responses from the perspective of sustainability.

- From the study cases, students will write a report, and discuss the issues of sustainability.
- If there is availability in terms of time, students will have opportunities to present their reflection on the case studies.

Appendix G.9 Expert 9 – Denmark

Name	Associate Prof, Dr. Jens Frederik Dalsgaard Nielsen
Background	Automation and control
Institution	Aalborg Universitet
Department	Electronic systems
Country	Denmark
Date of interview session	October 2012

Ranking tasks:

1	The fundamental concept of sustainability	6	Stakeholders
2	Engineering quality	7	Environmental management
3	Environmental assessments	8	Local issues
4	Economic aspect	9	Global issues
5	Resources and eco-systems	10	Engineering ethics

Feedbacks on ranking task:

- Because without having knowledge about sustainability in the long term you will raised problems, so I should turned the important to have some ideas and knowledge in that area. So people can also evaluate their own solutions of proposes for not in the long term but for more you know in the long term perspective.
- That also cause for the next one will initiate some space or in terms of quality because these two are very close related I think if it don't have quality solutions you cannot have the solution that will last for a long period of time
- If you don't have economy in your solutions then you will not have the possibilities to do solutions because there should be some kind of economy and I think economy aspect and not just economy because these are 2 different things.
- But you need to be able to make high quality solutions that are sustainable based on knowledge about the environment assessment and there should also be economy aspects so that is I think the 4 first that are very close related together and also no 5 because there you talk about resources and eco-systems which is basically the same as no 3 I think.
- I don't think they need to know about local problems then they need to know about problem because I think if there is hard in this case try to solve fine problems than it does not matter if the problem is located physical within 10 km in your Aalborg or it is Africa. We have project where people is running, the first year trying to make a sun driven in Tanzania in Africa.so I don't think local problem is the way to go.. Well this is a good project because the problem they were to work.

Sustainability incorporation in engineering education

- So first semester is quite special. Then another thing about first semester is that I think that we should be aware of what has driven the student to come here to take an education as an engineer. And in the first place I don't think that it is necessary all the non-technical parts.
- They are coming because they are technical interest and they are quite young, so I think that may be some of the stuff that are are today on the first or second semester in the non -technical part should may be moved to later semester so let come to the university... let them learn some technology and get some experience do the project work and then we can come later when they have grown little big more up and more mature inside the heads and then we try to impose these ideas.

- Knowledge is difficult to learn and we should be aware of that we are not stressing it too much. So this is not an engineering stuff this is some just other kind of study. Terrific part it is nice in the first semester but somehow of its should be beyond fix semester and be mandatory for many student because fix semester they are maybe 21 to 22 years old and then they are much more grown up and much more adaptable to this kind of teaching but this might not be true but this is at least my opinion.
- so we need to give them scales so that can do engineering work in the beginning and then later we can maybe come back and do much more about assessment in for non-technical view angles.
- The case now I'm running 2 projects at the first semester, one about energy system for houses. And this is very much about sustainability and about energy saving and the other one is a project where they want to measure pollution on the farmers field coming from fertilizers and this also has a very long term perspectives because we want to see how the farmers grown of crops in his fields will change evaporations of different chemicals natrium oxides etc. from the soil and make solutions of that is cheap and that can run for years and robots trying to solve a or one major society problem.
- I try to push them in different direction and put out some open question. Could be a wise to take a look and this thing, could be a wise to take a look something in like a life time of the batteries because there are also some environmental aspects if you go to change batteries every year at least a major part of pollution in today because of the metal that are inside batteries and so on and should also be to robots as well and not just end up like garbage in the irrigation system. So that's only a very small step.
- So i think this assessment should be covering or at least try to cover both areas because assessment non-technical parts it should also have the technical parts because otherwise i think they will not reflect how to adapt the technology to non-technical. But it is not so easy and then one more thing this is not necessary relevant to all kind of project.
- they are like international conference so they have to learn on how to write a remarkable on this and make short, precise presentation, problem with the solutions and long term perspectives and so on and have to present it in our auditorium, it is like a conference where every group 20 minutes like winner all of us will going for conference out in the world.
- So this is a non-technical part of the seventh semester on how to do it in scientific ways and how to inform the world about what you will do in an organize structure.

Appendix G.10 Expert 10 – Denmark

		
	Name	Associate Prof, Dr. Ole Kiel Jensen
	Background	Antennas, propagation and radio networking
	Institution	Aalborg Universitet
	Department	Electronic systems
	Country	Denmark
	Date of interview session	October 2012

Ranking tasks:

1	Engineering quality	6	The fundamental concept of sustainability
2	Resources and eco-systems	7	Environmental assessments
3	Global issues	8	Engineering ethics
4	Economic aspect	9	Stakeholders
5	Environmental management	10	Local issues

Feedbacks on ranking task:

- Fundamental concept of sustainability is not much considered on every day used
- We often not working on local problems,
- If we look at education point of view, engineering quality and economic aspect should be considered in finding engineering solutions.
- Criteria set by stakeholders are not so important for education point of view, but students should consider the criteria in industries.
- They have to make a good quality product when they go to company. I f the quality is bad, you are out of business. So I think that is fundamental.
- In some cases, resources and eco-systems are important, but to some cases are not.
- In many cases, the companies that work with global market or global relation, engineering solutions for global issues are important.

Sustainability incorporation in engineering education

- We gave them some toys (LEGO mind storm systems), they make a robot and make it competition. So it was a competition amongst group.
- So the students working together.
- They have to find a problem, investigate the problem and find the solutions.
- This one is for kids that are handicapped, deft and mute, and then we have a school for this. Some teacher they want a system that activate the students. They made an interactive wall… They want some games that connect the students.
- We have couple of meeting with teachers from the school, discuss the ideas how we could make that, so…they made analyses and made specification on the products in more schematic way.
- We make catalogue where we have some proposals, provides some general descriptions and requirements.
- Sometimes the students bring their own proposals.
- We have to make proposal fit to the frame of the study regulations. So that the only limitations for preparing proposals.
- Most of students conduct some sort of interviews and distribute questionnaires to make analysis on social aspects.
- They analyze requirements set by the companies, and try to find out how should the product work,

what are the requirements should be fulfilled for that product to be applicable.

Appendix G.11 Expert 11 – Denmark

Name	Professor, Dr. Arne Remmen
Background	Sustainability, Innovation and Policy
Institution	Aalborg Universitet
Department	Planning
Country	Denmark
Date of interview session	October 2012

Ranking tasks:

1	The fundamental concept of sustainability	6	Stakeholders
2	Resources and eco-systems	7	Engineering ethics
3	Local issues	8	Engineering quality
4	Global issues	9	Economic aspect
5	Environmental issues	10	Environmental assessments

Feedbacks on ranking task:

- There are some components in parallel,..the are important. You could see what I have been ranking is the most important was some of the basic understanding.
- As engineering education this is about solutions, but in order to make solutions, then you also need to understand the problems. Problems and solutions are interlinked, but in order to understand the problems and the solutions, you also need some basic understanding sustainability, not just the three dimensions but the institutional aspect.
- Fundamental concept is you are able to do on all three aspects,
- Very often of engineers that only focus on one dimension, and if we have a perfect solution, they think then the rest will follow. That is not true.
- It is extremely important for engineers within industries to understand the technology are not good or bad per definition; you have to find out, to create institutions that are able to make solutions.
- All the issues related to climate change showing that we have a problem with institution in the global scale to handle the problems. That are the cause a lot of solutions are not working properly.
- The one that I haven't ranked higher is more tools based. Is not saying that the tools are not important. Of course, good to know the economic tools, also to understand again the economic aspect is part of the concept.

Sustainability incorporation in engineering education

- I tried to do, not just to teach organization theories, but try to illustrate from my real experience working together with different enterprises.
- You can see organization as a machine, where you can optimize, and find the right speed. So people are not having work problems.
- Or you can say, organizations are social identity, they are taking all the social aspects. The social relations, competences of people. Organization consists of people.
- And see organizations as part of interacting to the stakeholders. Organizations are depending to that contact.
- They depending on the market, depending on the regulations, very mush depending how good they are interpreting of these aspects.
- We have three areas of performance. We have research, we have education and we have the

innovation, outreach. We are over performing on most of them. In that sense you could say, the main problem that people are over busy.

- We have interesting project like cross-cutting different programs. The main problem we have in education part is to really difficult to attract Danish students.
- We are now a step beyond learning about sustainability.

Appendix G.12 Expert 12 – Denmark

<table>
<tr><td rowspan="6"></td><td>Name</td><td>Associate Prof, Tom S. Pedersen</td></tr>
<tr><td>Background</td><td>Automation and control</td></tr>
<tr><td>Institution</td><td>Aalborg Universitet</td></tr>
<tr><td>Department</td><td>Electronic systems</td></tr>
<tr><td>Country</td><td>Denmark</td></tr>
<tr><td>Date of interview session</td><td>October 2012</td></tr>
<tr><td colspan="3">Ranking tasks:</td></tr>
</table>

1	Resources and eco-systems	6	Engineering ethics
2	Global issues	7	Stakeholders
3	Economic aspect	8	The fundamental concept of sustainability
4	Engineering quality	9	Environmental management
5	Local issues	10	Environmental assessments

Feedbacks on ranking task:

- Engineering solutions considering the resources and eco-systems – it is not something conceptual – suitable to incorporate in engineering curricula that is more focus on providing solutions, not to understand the concepts or the reasons.
- As an engineer, we always prefer to create engineering solutions that are realistic and something are not extreme, something that can put into practice.
- I am not sure about the concept behind Sustainability. I think most people have some ideas about sustainability.
- The knowledge of environmental management and assessments are more on conceptual level which I think not focus on implementation, which the level engineers looking for.
- It is important to incorporate engineering ethics on engineering curricula, but not as a special topic. Integrated into the existing courses.

Sustainability incorporation in engineering education

- We in electronic department are more focusing on technology for sustainability.
- We dealing with:
    - Smart grid
    - Wind turbine
    - Wave energy
- We providing technical skills and engineering solutions related to sustainability

Appendix G.13 Expert 13 – France

Name	Professor, Peggy Zwolinski
Background	Renewables and Environment
Institution	Universitè de Grenoble
Department/CoE	GSCOP Laboratory
Country	France
Date of interview session	November 2012

Ranking tasks:

1	The fundamental concept of sustainability	6	Engineering ethics
2	Global issues	7	Environmental management
3	Resources and eco-systems	8	Engineering quality
4	Environmental assessments	9	Economic aspect
5	Stakeholders	10	Local issues

Feedbacks on ranking task:

- Fundamental concepts of sustainability are very important and perhaps it followed by the engineering solutions for global problems based on current position. From my experience, when we teach environemntal aspect, it is difficult to enlarge or to link it to sustainability. So perhaps it could better first to put a lecture on global problems and then to describe things about environmental aspects and economical aspect and quality aspect.
- I think environmental management easy for engineer, so we have to put it after. I think it is because we have many standard. In fact, because there are many standard they(engineer) can learn by themselve. Perhaps from companies.
- Perhaps, I think the local problems are very accessible, easily find something in your area of interest. You get many information regarding to the local projects. I think in the line of students in France, we are more toward engineering solutions for local problems and we are nearly missing the components how to solve the global problems.
- Engineering solutions based on economic aspect and quality has been teached for so many years to our students. That why I ranked these two components at rank 8 and 9th. However we have to teach these two components to the students, we know more or less how to do this. I think in company or in many engineering solutions, its always has consideration about economical aspect and quality. For companies, engineers and engineer students, they always in the same line(perspective). So it is not because it less important, but it is because it always be considered. So perhap the focus should be to another point of view and make a change in their mind.
- I think it is quite hard to prioritized because everything is necessary to achieve sustainability. We know that in order to every time we talk about quality, we dont talk about ecosystem. So perhaps we have focus more on ecosystem that may not present in our knowledge.

Sustainability incorporation in engineering education

- We have a few professor in this field. Before this we didn’t teach courses about sustainability and it is not very easy to create a course for sustainability. What we have is, we have a collection of courses which are element of sustainability such as design, management.
- We already open a position for professor in this area, and we starting to develop courses for learning about sustainability.
- So what we did, we create a committee to develop curriculum for sustainability. We have to axis,

one is about training. How to teach sustainability. and another one is how to be sustainable. We cant teach students what to do if we didn't do it. We have to make an action. In this committee, we are people from human scientist, economist, students, administration, other stakeholders. First we design a curricula for the school. and then for the teachers. As I said, we don't want to have a specific lecture about sustainability. We want, the teacher includes small portion in their curricula at the beginning of the year (one day seminar) and finally at the end, the students will learn again about sustainability and can make a choice for this field further.

- What we want to do is to create a specific day, and its already work in some universities in France. They create specific day, sustainable day, and we bring the students. It is just initiation. We have three hundreds students. In this day, we explained students about sustainable committee, the actions taken in schools, and we have two hours lecture. The lecture realized by French association using several case studies to explain what is sustainability.
- We also organized a special lunch, with a local products. Try to think about the food. and in the afternoon we have ten small sessions regarding other aspects in sustainability. Such as ergonomic aspect, economic aspect, collaboration with companies and so on. Just to open the mind of students.
- Then they have difference lecture about other aspects such as quality and so on. At this stage, we have to convince our colleague that they have to put in their lecture, something to highlight and link to sustainability. At the last, students will have final lecture about sustainability (after three years).
- Completely true. That why we didn't ask all teachers to integrate sustainability. What we did, we select a group of teachers that have lectures which are more related to sustainability and depending on the teachers. Some of them are already in the committee.
- What we think was, we want to take benefit from case studies in the companies, and we want to show to our students and teachers that it is really important for us(teacher) to teach sustainability because it is a need in the companies.
- Couple years ago, we are studying about water issues, at that time no one interested in research on water. But now everybody is interested studying in water. Could be the same thing for sustainability. We start to communicate, to identify project. But as I said, we don't have the knowledge to really teach it like theoretical lecture so we have to construct this working with companies, working with teachers and students. So same thing we try encourage students to realize sustainable project.
- For example, we announced for sustainable day that will be a price for the best project in sustainability. We try to motivate people to consider it, and we need company case studies because for long time people talk about sustainability, environment and etc. Sometimes students are fed up on everything and they don't really, they understand it is important, because there are no solutions to solve thing perhaps they little bit fed up with amount of work. We have to motivate everyone, and we have to back to community at try to show the best on how to apply sustainability.

Appendix G.14 Expert 14 – India

<table>
<tr><td rowspan="6"></td><td>Name</td><td>Professor, Rangan Banarjee</td></tr>
<tr><td>Background</td><td>He is a Convening Lead Analyst for Industrial End Use Efficiency and a member of the executive committee for the Global Energy Assessment (2008-2011) coordinated by the International Institute for Applied Systems Analysis. He was a member of the Working Group on New and Renewable Energy for the Twelfth Five Year Plan (2012-17) of Ministry of New and Renewable Energy .He is on the editorial board of Energy for Sustainable Development, International Journal of Sustainable Engineering and International Journal of Thermodynamics. He is involved in a project ‘Development of Megawattscale Solar Thermal Power Testing, Simulation, Research Facility’ sponsored by Ministry of New and Renewable Energy, Government of India, New Delhi.</td></tr>
<tr><td>Institution</td><td>Indian Institute of Technology Bombay</td></tr>
<tr><td>Department</td><td>Energy Science and Engineering</td></tr>
<tr><td>Country</td><td>India</td></tr>
<tr><td>Date of interview session</td><td>February 2012</td></tr>
<tr><td colspan="3">Ranking tasks:</td></tr>
</table>

1	The fundamental concept of sustainability	6	Stakeholders
2	Global issues	7	Environmental management
3	Local issues	8	Economic aspect
4	Resource and eco-systems	9	Environmental assessments
5	Engineering ethics	10	Engineering quality

Feedbacks on ranking task:

- First thing we have to understand, what is we are talking about sustainability. What are the issues related to different generations. What is it we want the population have certain quality of life. Until the students understand the motivation, it is difficult to come out with. It is not just a question saying what is the goal. Why we trying to get this? Right now we haven’t have very well definition of sustainability.
- For me two (global problems) and three (local problems) are interchangable for me. Half of sustainability issues has come up in term for resources sustainability and greenhouse gas problem which are global problem. Carbon emission and quality of life are also. We also look at in local problems.
- Is actually questions of hierachy of needs. If you look at the basic need met, then we look at global problems. If you look at sustainability problems, you can have some of the things from other ecosystem. So you are really looking at global problems.
- Economic aspect is very important to engineering field, but when we talking about sustainability,market maybe distorted and then new technologies the economic maybe wether early technologies or matured technologies, if you look at technologies being applied, yes economic system will be major issues. But if you look at longer term solutions, economic will give you part of the picture.

• Economic aspect is already there in system. You know for instance something is not very economic today, but part of sustainable solutions if you do it in larger volume.
Sustainability incorporation in engineering education
• We have many courses that related to some components in sustainability. Either it related to energy or environment. We have a compulsory course, which this has happened through public interests. We have courses for environmental engineering.

Appendix G.15 Expert 15 – Spain

Name	Professor, Didac Ferrer Balas
Background	PHD in Engineering and Materials Sciences from the Polytechnic University of Catalonia (UPC) where as a professor, researcher and director he has been responsible for different initiatives, policies and strategies in the field of sustainability since the year 2000.
Institution	Universitat Politècnica de Catalunya
Department	Centre per a la Sostenibilitat
Country	Spain
Date of interview session	February 2012

Ranking tasks:

1	The fundamental concept of sustainability	6	Local issues
2	Resources and eco-systems	7	Global issues
3	Stakeholders	8	Economic aspect
4	Engineering ethics	9	Environmental assessments
5	Engineering quality	10	Environmental management

Feedbacks on ranking task:

- I definitely think that sustainability is a way of thinking. It is systems thinking. This is very much needed for the rest of items. If you don’t have the capacity of thinking in systems or in complex or in long term. You hardly deliver solutions that are useful and etc.
- It is important to start with the fundamental before looking into the details.
- The other aspects, considerations on resources and eco-systems, and stakeholders, are fundamental to sustainability compare to the situation today, where engineering education is mainly driven by economic and by technology, available technology, this would be the way to balance it. So considering environmental limit and the social side of engineering which is stakeholders are the way to compliment and balance the traditional focus of engineering education.
- In general, engineering practices in company setting and prioritize the economic revenue and liability of any project. Unless there is individual commitment amongst engineers to reverse this trend that focus only economic.
- Environmental assessments and management are techniques that you can learn if you involve in environmental in engineering, you take specialization in assessment, or etc. But is not in the fundamental of the learning of sustainability.
- For example, the social issues or the long term issues, which are link to participation , decision making and etc. are sometimes are more relevant then assessments or management.
- I could consider, local issues not so well represented and also our engineers, if they think progressively and it better to start from local and continue to global. It easier to tackle smaller project that less complex than the hyper complex.

Sustainability incorporation in engineering education

- I have been involving in developing policies in integrating sustainability through all activities in higher education in the university.

- One big issues is the curriculum, how to embedding sustainability.
- I have been participating in various processes in developing curricula; fundamentally we need some kind of overarching goal in embedding sustainability.
- Double edges strategy, where you need modules that are quiet explicit in sustainability, and another courses that integrate sustainability.
- In the first year, we have courses to talk about sustainability, the limits, the fundamental concepts, the state of world, the different area where issues of sustainability is more critical.
- All the fundamental challenge is creating culture of the importance of sustainability in all curricula. So from any discipline recognizing that, there are various challenges that they can tackle and plenty of problem that engineering fields is creating. So this double edges, effect the intersection between engineering and sustainability.
- Obviously, PBL or active learning is fundamental to learn sustainability. we talking about transformative learning, we talking something that affects not at least the knowledge, it is something that transform your vision, attitudes, values and skills. This is possible through learning by doing, hands-on learning, role playing and etc. so all these different techniques where you get involve as human being, as a person, not just a brain.

Appendix G.16 Expert 16 – The Netherland

	Name	Dr. Ir. Karel F. Mulder
	Background	He was the initiator of the series of Engineering Education in Sustainable Development Conferences that took place biannually from 2002. Karel Mulder lectured at various universities abroad and cooperates with several Sustainable Development units at Technical Universities throughout Europe. He published recently the book 'Sustainable Development for Engineers' and authored various papers regarding the role of technology, technological innovation and technological education in Sustainable Development.
	Institution	Delft University of Technology
	Department	TBM – Technology dynamics and sustainable development
	Country	The Netherland
	Date of interview session	February 2012

Ranking tasks:

1	The fundamental concept of sustainability	6	Environmental assessments
2	Stakeholders	7	Local issues
3	Resources and eco-systems	8	Global issues
4	Engineering ethics	9	Engineering quality
5	Environmental management	10	Economic aspect

Feedbacks on ranking task:

- I think very often I see they do not know the fundamental concept at all, they think they know what is it.
- One if the basic laws, whenever they recognizing the compelling needs for sustainable development, they try figure out and struggle all by themselves, and of course developing the solutions cannot be done just by the engineers, by themselves. After recognizing the needs for SD, you should right away recognize that we have to work jointly to finding solutions. You need all the experts all the stakeholders.
- Engineers do not recognized that technological designs or technological choices have moral, political consequences.
- I don't think economic aspect is unimportant, but economic are very often already so much integrated in engineering designs.
- Students should learn that in the long terms, economic aspect adapts to sustainability.

Sustainability incorporation in engineering education

- We should introduce the basic course on sustainable development for all students
- We integrate sustainability in the existing engineering curricula
- We create options for specialization for students who want to specialize in SD
- We found out that engineering teachers hate to be told. The professors do not want to be in class with students. So we asked teachers what are you doing about SD, what your discipline or field of expertise

would contribute to SD, so that was quiet successful. Because all professors are very proud of their discipline, they always feel that their field of expertise is more important than the others.

- So we talking and talking to the professor, and we started to explain SD,
- So from all the interviews, we make a seminar and discuss what are the issues in the curricula, so it is quiet working, because all the teachers are involved.
- So for students in Delft, the specialization course is known as a bot week. It is a course for one week on the boat, we sail around the Netherlands. Students are working on the sustainable project based on the preference that they set up as a goal in the future. They visualized the project in the future time, and bring back from the longer term to your recent project, and find solutions how to contribute to more sustainable in the future.

Appendix G.17 Expert 17 – Switzerland

Name	Professor, Claudio Boër
Background	Director of the Institute CIM for Sustainable Innovation. Member Of The Board at SUPSI, Professor at GDUT, Senior Advisor at swissnex China, Advisor at Governor of Guangdong Province
Institution	University of Applied Sciences and Arts of Southern Switzerland
Department	Institute CIM for Sustainable Innovation
Country	Switzerland
Date of interview session	March 2012

Ranking tasks:

1	Stakeholders	6	Resources and eco-systems
2	Environmental assessments	7	Local issues
3	Global issues	8	The fundamental concept of sustainability
4	Economic aspect	9	Engineering quality
5	Environmental management	10	Engineering ethics

Feedbacks on ranking task:

- If the stakeholders are not involved in finding solutions, well you will always face problems. The criteria that set by the stakeholders become very important.
- If you are the one referring engineering solutions, you cannot just let the stakeholders set the criteria all by themselves. You help to drive these criteria.
- It is very difficult to assess the impact on environmental. Whatever it is, product, process,. You need very well to know how to assess environment. We have been working on sustainability for a long time, now what we really doing is try to assess sustainability, not only environment. This is really something that we are convinced very important. If you cannot assess sustainability with number, it will always very difficult.
- If you have engineering solutions are to solve global problems, than you can adapt to local problems. Not vice versa.
- In our society, everything is still driven by the economic. Even sustainability, has to be driven by the economic aspect. If you want your engineering solutions are successful, you need to consider the economic aspect.
- Nowadays, more or less, everybody knows what the fundamental concept of sustainability is. The concept of three pillars, the cradle-to-grave, and etc. If it is develop for students, so it is clear that the fundamental concept of sustainability is important.
- Sustainability should be thought at the first year of engineering program.

Sustainability incorporation in engineering education

- We teach only the fundamental concept of sustainability amongst engineering students. This due to the complexity of the existing engineering curricula.
- We don't teach them how to make solutions based on the others components of sustainability.
- We are working for master level, we develop on specialization for science and engineering that will be on environmental technology. And there we have more specific courses that tackle many of the

components of sustainability. That will be much higher in terms of number of credit.

- We try to teach engineers in the professions to apply sustainability when they work for the industries.
- We started to work on very specific component in sustainability such as in environmental aspect. For example waste to water treatment, recycling waste, and etc.
- Most of the transformation in engineering curricula is taken by individual initiatives.
- It is very difficult to make a change in bachelor level; you have to teach the basic of engineering to the students. If you teach the master students, then it became little bit more easily because our master students, they have to have applied research together with professor and industrial partner. They are ready to think for solutions for industrial partner. Because sustainability becoming an issue for our industrial partner. So they get much more involvement in sustainability issues than the bachelor students.

Appendix H

Clustering items

The following are the tables that show the cluster of each item that have been used as a probing tool in research phase 3.

Table H.1 Cluster for role of teacher

Question number	Statement	Cluster
a.	My teacher determined the knowledge for me to learn	Role of teacher
g.	My teacher outlined the knowledge with some flexibility for me to learn	
m.	My teacher facilitated me in determining the knowledge I want to learn	
u.	I had a full liberty to determine the knowledge I want to learn	

Table H.2 Cluster for role of student

Question number	Statement	Cluster
b.	I participated in the lecture	Role of student
c.	I participated in my group discussion	
h.	I contributed in solving problem(s)	
n.	I participated in discussions with engineers in industry	
o.	I participated in peer teaching	
v.	I contributed in my group´s project	
w.	I participated in the seminar	

Table H.3 Cluster for role of learning environment

Question number	Statement	Cluster
i.	I acquired the knowledge of sustainability from listening to the lecture	Role of learning environment
x.	I acquired the knowledge of sustainability through discussions with my friends	
j.	I acquired the knowledge of sustainability through my group´s project	
p.	I acquired the knowledge of sustainability from solving a problem(s)	
d.	I acquired the knowledge of sustainability from listening to the panels in seminar	
y.	I acquired the knowledge of sustainability from peer teaching	

Table H.4 Cluster for role of learning materials

Question number	Statement	Cluster
z.	I learnt the knowledge of sustainability from course materials	Role of learning materials
k.	I learnt the knowledge of sustainability from case studied provided	
r.	I learnt the knowledge of sustainability from several people	
e.	I learnt the knowledge of sustainability from my own search	
s.	I learnt the knowledge of sustainability from materials provided in seminar	
aa.	I learnt the knowledge of sustainability from our industrial visit reports	

Table H.5 Cluster for role of the environment

Question number	Statement	Cluster
l.	I learnt the knowledge of sustainability in the classroom	Role of the environment
t.	I learnt the knowledge of sustainability in the workshops/laboratories	
ab.	I learnt the knowledge of sustainability in our discussion room	
f.	I learnt the knowledge of sustainability while visit several industrial companies	
ac.	I learnt the knowledge of sustainability in my own room	

Appendix I

Publications

Part of the PhD study, the researcher participated several international conferences and wrote several articles that have been published as conference articles. The articles are embedded in the chapter 3, 5 and 6 of this thesis.

1.	Arsat, M., Holgaard, J.E., and de Graaff, E., (2011). Stand-alone and interdisciplinary course design for engineering education for sustainable development. SEFI Annual Conference.
2.	Arsat, M., Holgaard, J.E., and de Graaff, E., (2011). Three dimensions of characterizing courses for sustainability in engineering education: Models, approaches, and orientations. 3rd International Congress on Engineering Education (ICEED).
3.	Arsat, M., Holgaard, J.E., and de Graaff, E., (2012). Effectiveness of sustainability in engineering education: Research methods. SEFI Annual Conference.
4.	Arsat, M., Holgaard, J.E., and de Graaff, E., (2013). Integrating sustainability in a PBL environment for electronics engineering. The 4th International Research Symposium on Problem-Based Learning (IRSPBL).
5.	Arsat, M., (2013). Key sustainability themes and competencies for engineering education. Proceeding of the Research in Engineering Education Symposium.

Stand-alone and Interdisciplinary Course Design for Engineering Education for Sustainable Development

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ABSTRACT

In order to embed ESD in the EE curriculum, several approaches has been introduced and practiced in higher education institutions. One of the approaches is to introduce a new ESD course as an add-on to the existing curriculum being either compulsory or elective and either designed for a single discipline or to fit across programmes. At Aalborg University (AAU), Denmark, which has a long tradition of problem based learning (PBL), a comprehensive sustainability course has been introduced to fit all students not at least across programmes but also across faculties of engineering, humanities and social science. At this stage the learning objectives and the course content is stated; whereas the experience from practise is yet to be explored. In this paper we discuss the proposed learning objectives and content of the AAU course based on a conceptual framework for characterising ESD courses and reported examples of other ESD courses of the same kind. The presented conceptual framework is put to practice, characterising the AAU course as a stand-alone interdisciplinary course with a consensual approach. The conclusion is that the conceptual framework can provide an awareness of the design features, which can be related to the overall purpose of the course. The analysis also shows that even among the same type of courses there is divergence in the learning outcomes and the content. Therefore, discussion between course developers and stressing the use of the same type of courses across institutional settings is strongly recommended.

Keywords

Engineering Education, Education for Sustainable Development, course design, learning outcomes and content.

1. INTRODUCTION

Technology cannot be deployed as if it had no environmental or societal implications. Engineers must therefore be key players in sustainable development, and exhibit responsibility as part of the social structure – they should not just act as isolated technical experts [1]. In 1989 UK Royal Academy of Engineering started to develop the Principles of an Engineering Design Scheme. This charter points out that a sustainable development will require significant shifts in behaviour and consumption patterns. Often it will be – and should be – engineers who are making the decisions about the use of material, energy and water resources, the development of infrastructure, the design of new products and so on. However, engineers must recognize and exercise their responsibility to society as a whole, which may sometimes conflict with their responsibility to the immediate client or customer [2].

The importance of Education for Sustainable Development (ESD) in the Engineering Education (EE) curriculum was recognised by UNESCO already in the year of 1975 and in 1992 UNCED introduced sustainability as a major principle in supporting human development. The Barcelona Declaration stated that the "world and its cultures need a different kind of engineer, one who has a long-term, systemic approach to decision-making, one who is guided by ethics, justice, equality and solidarity, and has a holistic understanding that goes beyond his or her own field of specialisation". Education can serve as a platform to produce a new generation of engineers and therefore higher education should be committed towards sustainable development [3].

Aalborg University Denmark, a higher education institute well known for its problem based learning environment, an ESD course is presently being implemented. The course is to be offered to all students across the faculties of Engineering and Science, Social Science and Humanities. At this stage the learning objectives and the course content are formulated, whereas the experience from practise is yet to be defined.

Scientists who are experts on sustainability construct the curriculum; however from the perspective of educational research in general and research on ESD in specific, the case offers opportunities to follow an ESD course offered across faculties and within a problem based learning environment.

In this paper will tell the first part of the story, by addressing the following question:

How can an ESD course be characterised based on the content and learning outcomes and to what extend is the AAU course in alignment with other ESD courses sharing the same characteristics?

In the following pages we will synthesise theoretical distinctions of ESD courses considering the content and learning outcomes. After that, we present the course content and learning objectives of the AAU ESD course; and discuss the characteristics of this specific course. Besides the case-specific conclusions, we also seek to provide a conceptual framework for characterising ESD courses in general.

Based on the characteristics from the AAU ESD course, we have selected two cases of ESD courses for comparison focusing specifically on the learning objectives and course content. These cases are based on a literature review of two articles with the same characteristics as the AAU course. The articles are selected through a screening of 25 articles on EESD. As the articles are chosen for exemplification, they by no means are to construct statistical validity for the dominant EESD practise of courses of that kind. Instead the articles are chosen primary to show the variety of learning outcomes within the same category of courses and secondary to provide feedback to the suggested course content and learning outcomes of the ESD course at Aalborg University.

2. CHARACTERISING ESD COURSES

The strategy for design of ESD differs from one institution to another, but however may share some of the same characteristics. In the following we present three theoretical distinctions to characterise an ESD course.

2.1 Stand-alone versus embedded models

Salih has pointed to two types of models to integrate SD; (i) a stand-alone and (ii) embedded model [4].

The stand-alone ESD model provides opportunities for students to develop sustainability skills through specific courses that are carefully planned for this purpose. To put it in more general terms:, stand-alone ESD courses usually do not affect other courses in the programme nor the institution or the educational paradigm [5]. Erdorgan and Tuncer in their article entitled Evaluation of a Course "Awareness for Sustainability" outlined five objectives of the course, characteristics of the stand-alone model [6]. In their stand-alone course, they define sustainability in terms of skills, knowledge and affection [6]. The course provides understanding of sustainability in daily life and work, as well as awareness of environmental issues, acquisition of social values, and personal views on sustainability and the natural life circle [6]. Other examples of the stand-alone ESD model can be found in the following references [7-11].

By contrast, the embedded ESD model integrates SD issues in the teaching and learning activities across the curriculum. This model does not require the student to take a specific course as in the stand-alone model. Instead the students are trained to relate traditional aspects of the disciplines to SD. The learning outcomes related to the SD will thereby be integrated as a part of the learning outcomes of the respective courses. A clear example of an embedded ESD model is reported in Boks and Diehl "Integration of sustainability in regular course: experiences in industrial design engineering" [12]. Another example is the course offered in TU Delft, labelled Technology in Sustainable Development, which is introduced as elementary ESD course integrating SD [5].

2.2 Disciplinary versus interdisciplinary oriented

Another distinction, which may be made in the design of ESD, is whether they are disciplinary-oriented or interdisciplinary-oriented.

A clear characteristic of a disciplinary-oriented curriculum is the focus on a strict interpretation of the disciplines with separate subjects and that no attempts are made for integration [13]. On the contrary an interdisciplinary-oriented curriculum deliberately brings together the full range of disciplines [13].

A disciplinary-oriented ESD course can be viewed as an add-on with a particular disciplinary focus, whereas the choice of content is decided by the relevance for a specific engineering profession as mechanical, civil, electrical or chemical engineering. The difference between disciplinary-oriented and interdisciplinary-oriented ESD courses is important in relation to understanding the course learning objectives. An example of a disciplinary-oriented ESD course is offered to ecological engineering programme by Arabaev Kyrgyz State Pedagogical University (KSPU) [7]. The course contents focus on ecological and environmental aspects including local problems, a code of ethics and nature disasters as most important elements and emphasized these aspects when discussing issues and topics regarding to the environmental impact [7]. Other example of disciplinary-oriented courses may be available in reference [9].

An interdisciplinary-oriented course curriculum is instead demanding cross-discipline implementation without changing or rearranging the course according to one specific discipline. In other words, an interdisciplinary-oriented course is compatible to a wide range of disciplines.

Sometimes course developers are able to design a course that serves all disciplines available in a University [6]. This approach demands a certain level of cooperation among course developers to work together in designing a course that is suitable and achievable for students from different disciplines. However, the interdisciplinary group of students might make it possible to address the complex and interdisciplinary nature of SD.

Course developers might also cope with the diversity by clustering disciplines in larger groups like Social Science, Technology, Engineering and Science. There are several universities that applied this approach to design an interdisciplinary course. This opportunity presents an easier way to select course content and deal with the experience that interdisciplinary content of ESD does not easily fit into a disciplinary-oriented educational process [14]. An example of this interdisciplinary-oriented course opens to students from all engineering disciplines can be found in the study of Hollar [8]. This course has adapted an active learning approach by grouping students across disciplines and assigning them with an interdisciplinary design project [8]. In this project, teams established network relationships among engineering faculty, university engineer and others parties [8]. The students were to propose and design a solution to reduce the CO2 emission from the university to reduce the impact on environment [8]. See the original publication for details [8].

2.3 Singular, dialectic or consensual approach

The case presented by Lourdel et al, shows that sustainable development can be represented by various approaches [15]. Table 1,0 presents an overview of the different approaches applied. Expanding on Lourdel's representation of the diversity of approaches to sustainable development, we would like to propose three dimensions of ESD:

1) pure economic, social or environmental approaches. These three approaches we will term *singular* approaches to ESD.
2) economic approach with either an environmental or social perspective, social approach with either environmental or economic perspectives, and

environmental approach with either economic or social perspectives. These approaches we will term *dialectic* approaches to ESD.

3) a holistic approach combining economic, social and environmental aspects, where the three pillars of sustainability are fairly presented and included [15]. For this approach we will adopt Lourdel's notion of a consensual approach.

These three approaches to ESD show different levels of comprehensiveness in the interpretation of sustainable development.

Table 1. Approaches to Sustainable Development content

Lourdel´s representation	Category
Environmental (Strong sustainability)	Singular
Social	
Economic (Weak sustainability)	
Environmental with social perspective	Dialectic
Environmental with economic perspective	
Social with environmental perspective	
Social with economic perspective	
SD consensual approach	Consensual

2.4 Conceptual framework for characterising ESD content and learning outcomes

When combining the three distinctions of ESD presented above, we have a conceptual framework for characterizing learning outcomes and course content; by asking the following questions:

1) Are the SD learning objectives or content embedded into courses or does it have a life of its own within the programme (stand-alone or embedded)?
2) Are the learning objectives and content focused at supporting a single discipline or a range of disciplines (disciplinary/interdisciplinary)?
3) What are the range of the learning objectives and content in regard to SD as a concept (singular/dialectic/consensual)?

In the following paragraph we will use this three dimensional framework to characterize the ESD course at AAU.

3. THE ESD COURSE AT AAU

In the spring 2011 the president of Aalborg University together with the faculty deans decided to offer an elective 5 ECTS course (corresponding to 150 hours student work) for all nine-semester students at the University. Researchers within the field of sustainability science were appointed as responsible for the course. In the course description it is stated [16]. :

"This course is designed for all master level students, regardless of academic discipline. The course is interdisciplinary in nature and will take its point of departure in students' backgrounds, their current studies and their future careers and professional life and how they can incorporate sustainability in their coming professions. Emphasis is therefore on creating an understanding of how different professions relate to and impact on the core aspects of ensuring quality of life and creating environments in which sustainable development is possible".

The course has several learning objectives; whereas it is stated that after students have completed the course they [16] :

- Have thorough knowledge of professional responsibility and accountability
- Understand personal roles and responsibility (e.g. as consumer)
- Understand professional and/or organisational roles (e.g. as engineer, manager or policy maker)
- Have thorough knowledge about developments in the environmental discourse (past – present – future), including environmental regulations
- Have thorough knowledge and understanding of relevant concepts, theories and models in relation to sustainable development and its inherent complexities
- Can understand and reflect, with a scientific basis, on the causes and consequences of un-sustainable development, as well as the ability to identify scientific problems in relation to these
- Can from her/his own professional perspective identify, analyse and assess sustainability related problems and consequences
- Can communicate and discuss broad themes that have particular relevance for sustainable production and consumption
- Can relate to work and development situations that are complex, unpredictable and require new methods of solving
- Can reflect on relevant sustainability metrics used for valuing sustainability
- Can independently take responsibility for own professional development and specialisation in relation to sustainable development

In the specification of content the following keywords are mentioned: Fundamentals of environmental, social and economic development; practical challenges and theoretical underpinnings of sustainable development and responsibility: individual, professional, and organisational responsibilities; global-problems/crises (climate change, biodiversity, food, economy), as well as national and local cases; the relationship between ethical and political assumptions; social cohesion and justice [16]. .

We will argue here that the learning outcomes and content of this course can be characterized as an interdisciplinary, stand-alone course with a consensual approach.

In the following, we will compare the learning outcomes and contents from this course to two courses of the same kind, which is reported in [10, 11]. This we will do to provide feedback to the suggested course content and learning outcomes for the ESD course at Aalborg University, and on a more general level to elaborate on the theoretical founded characteristics of this kind of ESD course.

4. Implemented stand-alone interdisciplinary courses with a consensual approach to SD

Analysing two cases, based on the literature review offers insight in the implementation of EESD stand-alone interdisciplinary courses with consensual approach. The examples have been selected from a screening of 25 articles within the field of EESD. The two examples show that learning outcomes and course content might differ within same type of courses.

The first case is the Climate, Sustainability and Society course adapted by developers from La Trobe University, Australia. The stated learning objectives for the course are that students will [11]:

- Develop a vocabulary of contemporary definitions and theories relating to climate, sustainability and society.
- Be able to synthesise provided information and deliver a reasoned view.
- Recognise and use the semantic base from each of science, social science and economics.
- Respond to contemporary news media and appropriate peer reviewed research literature to convincingly argue a point of view and convey arguments to peers.
- Use a variety of resources to research a topic and construct an analysis relevant to a given context, and
- Work in a team to develop a summary of this research, and to present it to peers.

There are four key topics in this course. First is the introduction of the concept of climate and climate change [11]. Second, students are confronted with the impact of society on the environment and of the changing impact of environment on society [11]. Third, students are exposed to three high profile public speakers providing a platform for economist and environmental scientist to discuss the value of water, and a sociologist and engineer contemplating the impact on society of water redistribution [11]. Fourth, the objective is to make students conversant in the debate on SD and enable to develop an appreciation of the complexity of the issue [11].

The second case, concern an EESD course offered at Michigan Technological University, entitled Engineering Analysis and Problem Solving, the course developer stated three learning objectives [10]:

"...students were introduced to the concept of sustainability and its importance in engineering. They learned that engineers need to consider the impact a technology or device will have during design, manufacturing, use and disposal phases of a product. They were introduced to the effect of lifestyle had on the environment by calculating their ecological footprint."

The course developer introduced sustainable development as a holistic concept by incorporating sustainability investigation of four frameworks; that is engineering achievements, ethical decisions, globalization and individual lifestyles [10].

In the engineering achievement framework, students will research one of the greatest engineering achievements of the 20th Century [10]. As an outcome of this research, students will report their study by outlining the history of an engineering achievement as well as the perspectives of this achievement [10]. They also were to report implications of the achievement in terms of social, environmental and economic aspects of SD [10].

In the ethical decision framework, students investigated and evaluated the ethical decisions in engineering by researching a case study [10]. Students are reporting issues of sustainability involved and suggest alternative decisions, which might be more sustainable [10].

For the globalisation framework, students were to introduce a global perspective on engineering solutions in their studies of ethics [10]. Students will investigate the differences between developed and developing countries in terms of sustainable technologies for water treatment [10]. Students will learn that "only technologies appropriated to the culture, skill level and environment of an area would be sustainable" [10].

In the individual lifestyle framework, the course developer incorporated activities of statistics, programming and ethics [10]. By these activities students are to learn to determine the sustainability of their lifestyles, which include calculating personal electricity consumption, carbon footprint and ecological footprint [10].

5. CONCLUSION

In this paper we have presented a conceptual framework for characterising ESD courses based on three dimensions (see figure 1):

1) Stand-alone versus embedded ESD activities.
2) Disciplinary versus interdisciplinary orientation of ESD activities.
3) Singular, dialectic or consensual approach to SD as a concept.

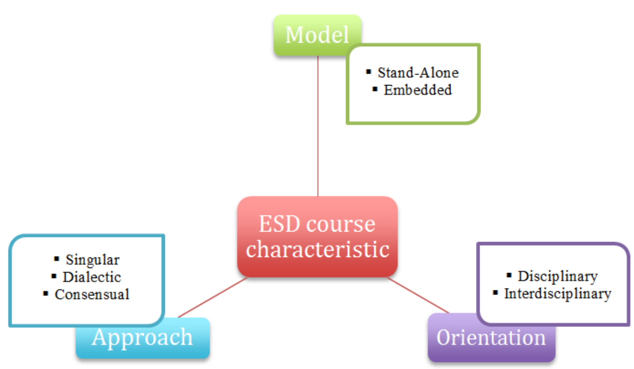

Figure 1. Dimensions to characterise the learning objectives and content of an ESD course.

The presented conceptual framework is brought into use when characterising the AAU course as a stand-alone interdisciplinary course with a consensual approach. In doing that, we have found that the conceptual framework can provide an awareness of the design features which serves as a platform for seeking inspiration in courses of the same kind.

However, the analysis also shows that even among the same type of courses there is divergence in the learning outcomes and the content.

When comparing the AAU course with two examples of implemented stand-alone interdisciplinary courses with a consensual approach it becomes clear that all though they can be characterised alike there are differences in their perspective. One seems more discursive in approach – focusing on providing the semantics and the argumentations for SD. Another course seems more product-oriented in its approach – focusing on the impact of products/engineering achievements in a life cycle perspective. The AAU course instead seems to take its point of departure in relating SD to the different professions.

Discussion between course developers emphasising the same type of courses across institutional settings is strongly recommended. An association like SEFI could serve as an appropriate framework for this kind of network activities.

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Three Dimensions of Characterizing Courses for Sustainability in Engineering Education: Models, Approaches and Orientations

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***Abstract*—Worldwide universities are changing their curriculum in response to the Barcelona Declaration. The adaptations include the integration of sustainability courses in engineering education. The various courses have been constructed with different kind of learning objectives and different interpretations of the sustainability concept. The paper introduces three dimensions of characterizing sustainability courses in engineering education; models, approaches and orientations. The paper reviews 30 articles and presents examples of sustainability courses that have been characterized based on the three dimensions. The conclusion is that the three dimensions of characterization can provide concrete perspectives on constructing and designing of sustainability course in engineering education.**

Keywords-component; Education for Sustainable Development; Engineering Education; Course Design

I. INTRODUCTION

Transforming higher education curricula for sustainable development (SD) is a tough challenge to the curriculum developer and course designer. They will have to deal with the complexness of the sustainability concept and integrate that into engineering education. Yet, many universities worldwide introduce SD in their programs. The section below highlights some of the most important international developments.

Universities in Japan initiated an effort to promote Education for Sustainable Development (ESD) as a part of educational transformation in higher education and the establishment of programs was formally outlined by Japan´s Action Plan in 2006 [1]. The education transformation manifested three types of ESD curricula at undergraduate level which are [1]:

i) Part of liberal arts and professional courses

ii) Newly formulated or existing course as minor course

iii) Establishment of ESD related departments

In India, implementation of the Decade of Education for Sustainable Development (DESD) has been assigned to the Ministry of Human Resources Development (MHRD) [2]. Education in India especially higher education has transformed in many different SD implementations in a variety of courses and programs [2]. The transformation is evidenced by the existence of new special programs (such as Master in Sustainable Development), Sustainable Development components were introduced into existing programs and various courses and modules related to SD were included in wide range of disciplines [2].

It is also important to acknowledge the effort of educational transformation for sustainable development at the University of Cambridge (UK). For example one Faculty has developed SD by introducing SD thinking into undergraduate teaching and has offered an MPhil degree in Engineering for SD [3]. In other research studies, three European universities present their effort of educational transformation with compulsory courses in traditional courses, new programs on SD and minor specializations for undergraduate and master degree [4].

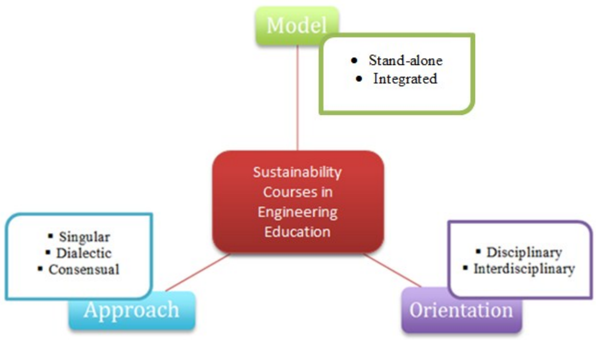

Figure 1. Three dimensions of characterizing learning objectives and course contents.

A study by Murphy shows that SD has been extensively incorporated in engineering programs in U. S. universities. Four main strategies are used to reform their courses and course modules, which are to develop dedicated SD courses, integrate sustainable engineering concepts into traditional courses, specific topic on sustainable technologies and interdisciplinary courses [5].

The challenge of designing or redesigning engineering courses as a part of an education transformation has inspired the author of this paper to reflect on the approaches used and to further develop a conceptual framework proposed by Arsat et.al [6] (see Fig. 1). The conceptual framework aims to characterize course learning objectives and course contents for sustainability in engineering education. This paper will discuss the conceptual framework and explain further the three dimensions. A total of 30 articles have been reviewed with the intention to reflect and characterize SD curriculum development by the three dimensions.

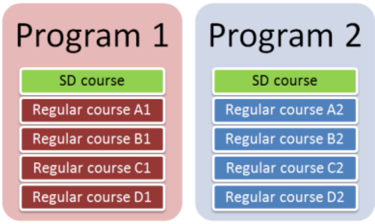

Figure 2. Stand-alone model: A SD course is introduced to both programs

II. MODELS

The first dimension to characterize course learning objectives and course contents consists of the two basic models. The two basic models proposed in this paper are the stand-alone model and the integrated model. The models have been developed through analyses of three cases of Salih[7], Sterling [8] and Segalas [9].

Salih recognizes two kinds of models of sustainability courses in engineering education, the stand alone and the embedded models [7]. Both models aim to implement sustainable development through the use of soft skills among Malaysian undergraduate students [7]. Sterling has stated that SD can be achieved by integrating or embedding sustainability as a part of engineering education programs; it cannot simply be an add-on to the existing curriculum [8].

Segalas stipulated that SD can be incorporated in engineering education curriculum in four different ways; compulsory courses, minor courses, introduction SD in the final year project, and intertwining sustainable development in all courses [9].

A. Stand-alone model

Generally, this model is applied at an early stage of curriculum transformation where a university introduces sustainability courses either incorporated or separate into the programs. The stand-alone model means that a course will be designed and constructed to provide understanding of sustainability with no intention to integrate this knowledge into the existing engineering courses. The advantage of this characteristic is that it is believed that the course can be applied to other programs and faculties without much adaptation. Fig. 2 illustrates a stand-alone model that is applied to a SD course for Program 1 and Program 2.

For example, a course entitled “Climate, Sustainability and Society” shows that its learning objectives and course contents can be characterized as stand-alone model. This course has stated six learning objectives. Two of the learning objectives are visibly related to sustainability [10]:

i) Develop a vocabulary of contemporary definitions and theories relating to climate, sustainability and society.

ii) Recognize and use the semantic base from each of science, social science and economics.

The course has introduced the concept of climate and climate change, confronted with the impact of society on the environment and of the changing environment on society, exposed to three high-profile public speakers, and debate and appreciate the complexity of sustainability issues [10].

Another course of the same kind is offered at Middle East Technical University, Turkey. This course called `Education and Awareness for Sustainability´ aims to help students to understand how the environment can be improved by adapting their daily life and work [11]. Students will also actively participate on activities related to sustainable development which social values, feeling of concern to environment and motivation acquired. The course integrates engineering, technology, health and science together with sociology, geography, history, management, literature and mathematics. All these elements are blended in lectures as well as in students´ activities such as discussions, brain storming and field trips [11].

Both courses mentioned above are purposely constructed for introducing the sustainability concept in engineering education and intentionally designed not to integrate into existing courses. With respect to the learning outcomes, the sustainability courses are designed for a general course, not aiming at specifics programs. Although both courses are characterized by the same basic model, the differences between both courses show how the sustainability concept can be developed in various ways. The first example shows that the sustainability concept can be developed by lecturing and debating the general issues of sustainability, while the second example shows that team working and field trips are used to put the sustainability concept to practice.

B. Integrated model

Conceptually, the integrated model is a model where sustainability elements integrate into regular or traditional engineering courses. This model requires course designers to revise and reconstruct engineering courses and adapt the sustainability concept to the needs of the curriculum. Therefore, the sustainability concept will not only be introduced to engineering fields but it will purposely be designed to the application, evaluation and synthesis levels.

Boks gives an example of integration of sustainability in an existing engineering course. The course, labeled Design 5, has been offered at industrial design engineering at Delft University of Technology, Netherlands for final year bachelor students. Design 5 is planned to encourage students to apply theories of `Product Development in Industrial Context´ and

This research has received support and fund from UNESCO Chair in Problem Based Learning & Engineering Education and Ministry of Higher Education, Malaysia.

`Market and Consumer´ as well as integrate sustainability into product design [12].

Figure 3. Integrated model: SD is incorporated to regular courses

Another example of an engineering course that is characterized by the integrated model is `Applied Sustainability and Public Health in Civil Engineering´. This course is offered to civil engineering students at Queen´s University, Canada [13]. The main objectives of the course are to evaluate global environment impact and public local impact of civil engineering design work as well as to apply concept and methods in LCA, EIO analysis and QRA [13].

Both examples show how sustainability elements have been integrated into the body of existing courses. The integrations can be realized on the sustainability elements, such as impact of environment and social skills, which cross over the engineering curricula. However the idea of integrating sustainability in every course depends on the question how much sustainability elements can be integrated into the existing courses. Sustainability is not an element in the final steps of engineering design, such as calculation of CO2 emissions. It is about a complete cycle of design, from the sketch until the real products.

III. Orientations

Orientations are the second dimensions that can be used to characterize course learning objectives and course contents. This dimension focuses on how learning objectives are formulated and how the choice of content is made from the pool of discipline knowledge. By contrast, the first dimension concentrates on the question how sustainability or SD can be constructed and incorporated to an existing program.

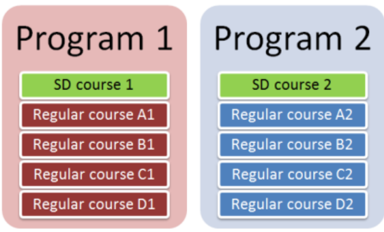

Figure 4. Disciplinary orientation: SD courses are constructed to fit to the disciplines

A. *Disciplinary orientation*

Disciplinary orientation can be described as a traditional method of subject teaching. The disciplinary orientation only focuses to provide learner with specialized skills and concepts in a field without any intention for integration [14]. Figure 4 shows sustainability courses that are constructed to fit within specific disciplines or a particular program. Normally, the programs offered at university are discipline oriented and the courses have been constructed to be relevant and to satisfy the program's learning objectives. In the field of engineering, most university has divided engineering disciplines into several programs such as mechanical engineering, electrical engineering, chemical engineering and civil engineering. Two sustainability courses that can be characterized as discipline oriented will be further explained.

In 2004, Arabaev Kyrgyz State Pedagogical University offered sustainability course for ecological engineering students and decision makers [15]. The course mainly focused on Central Asian ethnic problems, like nature conservation and nature exploitation activities [15]. Issues of sustainability have been incorporated to ecological and eco-technology such as hydroelectric stations, bio-gas machine, sun collectors for water boiling and room heating, and sun-drying equipment for crops and vegetables [15]. As an addition, the course developer includes emotional form using poetry and religion in the context of ecology [15].

Another example has been described in a research article in 2010 by Gardiner [16]. He presents a sustainability course that was offered to Industrial Engineering, and Information and System Engineering students. Basically, the course was designed to introduce concepts, methods and principles of engineering practice, problem solving, design, project planning, communication, team work, ethics and professionalism, innovative solution development and implementation. Several learning activities such as group work and forum discussions have been introduced to attain the learning objectives and suitable platforms has been provided for students to carry out research on topics related to sustainable development (managing Nitrogen Cycle, clean water, feeding the world, poverty, climate and hunger, solar system and etc.) [16].

Based on these two articles, the concept of sustainability has been introduced and developed based on the particular perspective of one discipline. Without cross-disciplinary content, the concept of sustainability is intentionally been focused in one engineering discipline emphasizing how an engineer in this discipline reflects on issues of sustainability. The articles show that the learning objectives and course contents have been narrowed down to ecological and industrial-system engineering disciplines without sacrificing any pillar of SD. However, it should be noted that the practices to put the general concept of sustainability into a corner of one specific discipline is at odds with the interdisciplinary characteristic of sustainability concept itself.

B. *Interdisciplinary orientation*

In contradiction to the disciplinary orientation, the interdisciplinary orientation "purposely brings together the full range of disciplines in the curriculum and uses a full array of discipline-based perspectives" [14]. The impact of a course with interdisciplinary orientation depends on the range between one disciplinary and other disciplines. A sustainability course that caters all four conventional engineering disciplines, mechanical, electrical, chemical and civil disciplines, has to deliver and satisfy all program learning objectives. Unlike combining two or three disciplines in the same pool of knowledge, constructing sustainability courses for a wide range of disciplines demand strong corporation and agreement on selecting learning objectives as well as course contents.

Fig. 5 illustrates position of a sustainability course is bridged from Program 1 to Program 2. The course can be single sustainability course or more, but implementation of the course(s) have to cross disciplines and no changing or rearranging of learning objectives are required according to specific discipline.

Hollar gives an example of an interdisciplinary oriented sustainability course [17]. The course has been offered to all engineering disciplines students at Rowan University. The learning objectives have been designed to meet the needs of workplaces such as technical knowledge, communication skills, and awareness of social implication, lifelong learning ability and ethical judgments [17]. The learning objectives are [17]:

i) Calculate greenhouse gas emissions for university.

ii) Propose low-cost solutions to improve energy efficiency.

iii) Propose alternative energy sources that can be incorporated into the future growth.

iv) Perform economic analysis (short term & long term).

v) Formulate a well support, articulate oral argument for using alternative energy sources.

This course has been prepared for engineering students to acquire the knowledge of sustainability by practicing real world problems, experiencing authentic engineering design project, such as designing a sustainable energy, and applying knowledge of economic. [17].

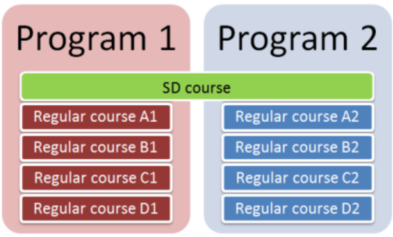

Figure 5. Interdisciplinary orientation: A SD course is purposely design for two different programs or more

Another example of an interdisciplinary oriented course is presented by Kemppainen [18]. Three objectives are formulated for this sustainability course.

- The first objective is an introduction to the engineering profession and to its various disciplines.
- The second objective is that the student will focus on developing problem solving skills, computational skills and communication skills.
- The third objective, student will apply engineering problem solving method to real world problems.

Case study and problem solving methods are instructional strategies used to covers general engineering topics and concept of sustainability. The course designer has also applied engineering achievements, ethics case studies, globalization and individual lifestyles as four frameworks to build up knowledge and skills of sustainability [18].

The interdisciplinary oriented courses presented above have shown that the course orientation can be attuned to the interdisciplinary nature of the sustainability concept. The learning objectives and course contents are achievable and suitable for a wide range of disciplines. However, mutual consensus has to be reached, to avoid imbalanced and unsynchronized between the course learning objectives and program learning outcomes.

IV. APPROACHES

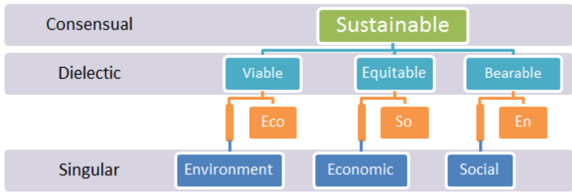

Figure 6. Comparison of the proposed approaches and sustainability concept

The three pillars of sustainability: environmental, economic and social factors are conceptually important aspects to be developed in engineering education. Complexness of the concept has opened up space for flexibility in designing a sustainability course in engineering education. This flexibility is demonstrated by the sustainability courses or sustainability-related courses that are offered all over the world in various engineering fields.

Sustainability is defined beyond than the integration of the three pillars. It is about balancing integration of those three key factors. However, the balance of integration of sustainability is not necessary tied to a single course but rather to program as a whole. A sustainability course that emphasizes the environmental pillars will be in a perfect equilibrium with other sustainability-related courses that emphasize the other pillars. This flexibility of design can be characterized into the third dimension: the approaches dimension.

The third dimension is also derived from the general model for sustainability [19] and Lourdel´s representation of sustainable development in [20].

A. Singular approach

The singular approach is described as sustainability courses that emphasize a specific pillar instead of a holistically blend of the three pillars together in a single course. Fig. 1 and Table I demonstrates that the singular approach is equivalent to environmental, economic and social approaches. A course that can be categorized as a singular approach is a course offered at most universities in Malaysia. The course aims to develop students´ understanding of the sustainability concept by the introduction of the impact of engineering interventions in terms of the engineering ethics, moral and values. An example of the singular approach can be seen in [21]. Most of the course content has been designed to emphasize on environmental issues in engineering works and small portion to introduce sustainable development concept.

TABLE I.
COMPARISON OF ARSAT´S AND LOURDEL´S APPROACHES TO SUSTAINABILITY

Arsat´s representations	*Lourdel´s representations*
Singular	Environmental
	Social
	Economic
Dialectic	Environmental with social perspective
	Environmental with economic perspective
	Social with environmental perspective
	Social with economic perspective
Consensual	SD consensual approach

B. Dialectic approach

The dialectic approach is defined as an approach that blends two pillars of sustainability to be the major learning component. A combination of the environmental with the social perspective is one of the possible combinations that can be made as an approach to sustainability. This is sometimes characterized as a dialectic approach, where the course targets are to influence students´ attitudes and practices (social perspective) in their daily life to be more environmental sensitive [11].The course is also a students´ platform to discuss real life cases (social perspective) from the street that they learned during a field trip. These activities on engagement to real story from street provide personal view of environmental issues. [11]. Lourdel also has presented four possible combinations of dialectic approach in his work as in [20].

C. Consensual approach

The consensual approach is an approach where learning objectives and course contents for sustainability course are fairly balanced in the integration of three pillars. The combination of pillars can be viewed as an example to both studies by Russell and Kemppainen as in [10] and [18]. Both studies were used in the development of the three dimensional SD model by Arsat et al. [6].

In term of learning objectives and course contents, both courses presented in [10] and [18] successfully balance the three pillars in a single course without compromising the core knowledge of the engineering curriculum. For example, Kemppainen's course [18] provides core engineering knowledge (e.g. computational skills, engineering problem solving method), economic (e.g. economic impact of the greatest engineering achievement in 20th century), environmental (e.g. calculation on electricity consumption, carbon and ecological foot prints) and social aspects (e.g. engineering ethics and global perspectives on engineering solutions).

These courses also prove that there are various methods to incorporate the concept of sustainability into single course. For example, the course presented by Russell [10] incorporates sustainability by presenting the three pillars as three different modules for one course while Kemppainen's course has blends all three pillars an one module. Evidently, there is flexibility of course design that is related to the complexness of sustainability concept. Program coordinators and course designers have to produce a framework that will guide the education transformation.

V. CONCLUSION

A wide range of course design and complexness of sustainability concept has opened up dimensions to characterize learning objectives and course contents for the development of sustainability courses. Based on the conceptual framework proposed by Arsat et al. [6], the three dimensions of characterization have been further explained and discussed.

The three dimensions of characterization can provide perspectives on constructing and designing sustainability course in engineering education. Models, orientations and approaches in characterizing of sustainability courses show evidence of variation in interpretation of sustainability concepts in engineering education. However, to compare between the demands of the sustainability concept and the three dimensions, it is shown that integrated models, interdisciplinary orientation and consensual approach might be ideal components for this purpose.

Supplementary research on effectiveness of models for the development of sustainability courses will be carried out at UNESCO Chair in Problem Based Learning and Engineering Education. In particular further study on the other two dimensions, orientation and approaches, is needed.

ACKNOWLEDGMENT

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Effectiveness of Sustainability in Engineering Education: Research Methods

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Conference Topic: Engineering Education Research

Keywords: Research Methods, Sustainability in Engineering Education

1 INTRODUCTION

The motivation of this research is to comprehend the changes in transforming engineering education, in particular to provide the next generation of engineers with sustainability attributes and competencies. The change includes integrating education about sustainability into existing engineering education, introducing a field of disciplines that specializes in sustainability and establishing engineering research on sustainability [1].

At the early phase of this research, two models for integrating sustainability in engineering education were identified. The models, the stand-alone and the integrated models, were presented as strategies in introducing of sustainability courses. Later, the attributes of the models were further developed considering findings and outcomes throughout the research processes. Sustainability courses in engineering education can be conceptually characterized in three dimensions comprises models, approaches and orientations [2]. This concept confirmed the existence of other kind of courses which were poorly structured and less effective. Hence, a number of engineering courses are effective in integrating sustainability in engineering education and some others are less effective. The existence of unbalanced courses motivated this researcher to study the effectiveness of courses for sustainability in engineering education.

2 RESEARCH METHODOLOGY

The main expected outcome of the research is to design a framework that will integrate sustainability in engineering curricula. Subsequently, the framework will provides course developers with important elements to integrate sustainability in designing a course. Furthermore, the framework also will offers course developers structured design procedures and inspires developers with the positive effects of the teaching methods. To achieve the research outcomes, several real experiences and effective courses will be evaluated and analyzed, and the results then will be presented as the design procedures and exemplary teaching methods.

A mixed methods design was employed to obtain data from a group of course developers, teachers and students. A part of this study, qualitative data are viable in addressing research problems in which interview transcripts and observation reflections can ascertain the process of developing the courses. Document analyses also are very helpful in providing important inputs. In the other part of this study, quantitative data are feasible to address research problems such as to determine the effectiveness of the courses. The combination of qualitative and quantitative data provides a thorough understanding in addressing research problems, in particular to provide complementary qualitative data if quantitative data are inadequate [3].

2.1 Research questions

The main research question for this study is *What are the characteristic of effective course design for integrating sustainability in engineering education?* This overall research question was further defined with other two subsequent research questions (i and ii) and three background questions (iii to v).

i) To what extend the structure of stand-alone course effective for integrating sustainability in engineering education?
ii) To what extend the structure of integrated course effective for integrating sustainability in engineering education?
iii) To what extend pedagogical strategy can be effectively integrate sustainability on both course structure?
iv) To what extend principles of sustainability can be effectively integrate on both course structure?
v) To what extend competencies of sustainability can be effectively integrate on both course structure?

3 RESEARCH DESIGN

3.1 Research model

Fig. 1 shows a research model which has been developed for this research. The research model was developed by adapting the basic cycle of design, investigate-plan-develop-evaluate, and will be used as overall research model. The cycle of the research model consists of four phases which includes qualitative and quantitative research methods. For phase one, the framework for course design was developed by reviewing sustainability courses across continents and collecting real practice feedbacks from experts and practitioners in sustainability. Outcomes from the phase one will serve as a base in developing instruments for the next phase. Two of the phases, phase two and phase three, will be focused on developing the framework for course design. Two case studies will be conducted at the phase two. It is expected that the in-depth case studies research will be able to point out the potential variables used to develop evaluation tools and indicator as well as to redesign the framework.

The phase three is the non-experimental research approaches. At this phase, effectiveness of five selected sustainability courses will be evaluated and indicated. Three types of evaluation tools to evaluate the effectiveness of sustainability courses were identified. The evaluation tools will use numerical values for evaluating the students´ learning outcomes in term of knowledge, skills and attitudes. This non-experimental approach intended to evaluate the offered sustainability course without intervention on existing course design. Therefore, the real practices can be justified and be the solutions of the main research question, which is to construct effective frameworks of course design.

The final phase is set in place to conduct validity tests on the proposed frameworks of course design. The proposed frameworks are used to develop an effective sustainability for both types of course structure. Two groups of course designers were assigned for the tests. The outcomes of the tests are feedbacks on the framework design.

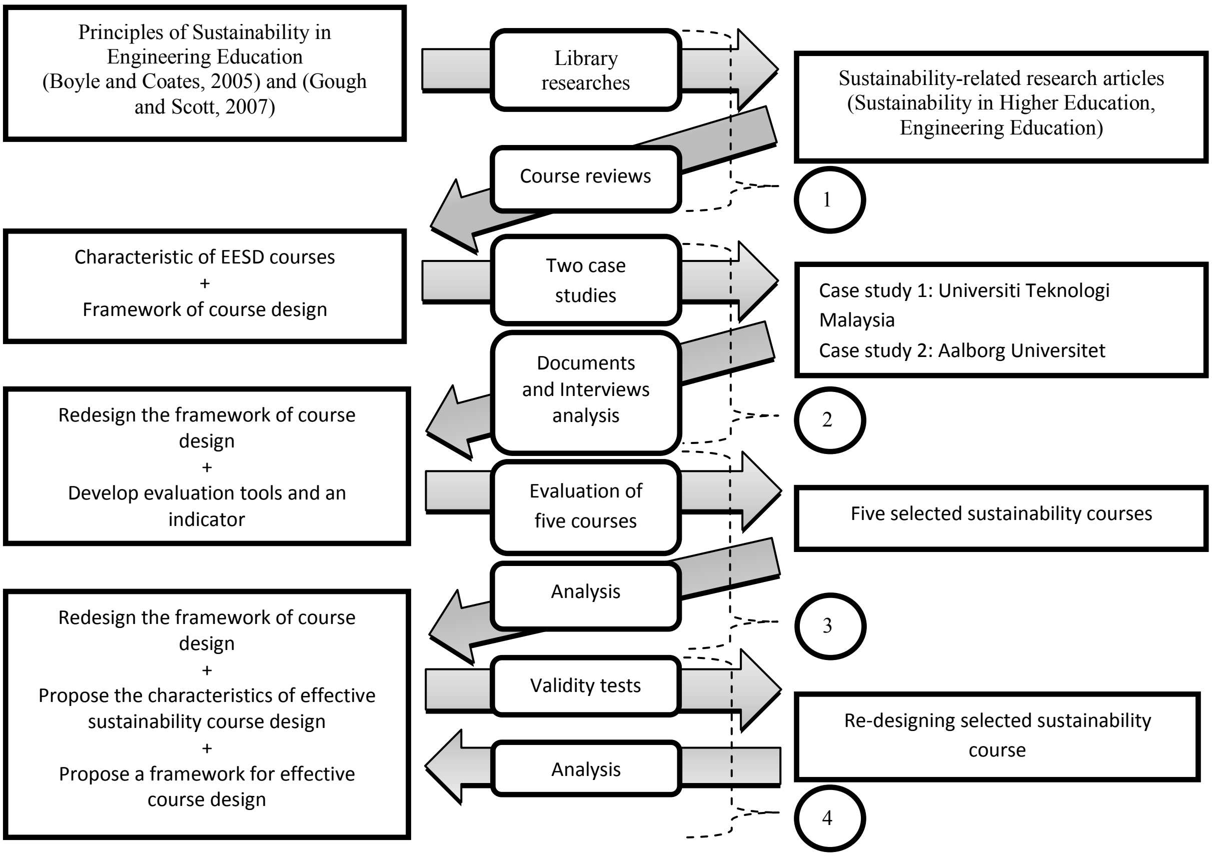

Fig. 1. Overall research model

3.2 Phase One: Exploring real world practices

This exploratory mixed methods design aims to get an overview of sustainability in engineering education and practical point of views on how experienced higher institution integrating sustainability in engineering curricula. A qualitative data was collected from accessible data bases and the data was analysed thematically. In this process, two set of concepts regarding the sustainability in engineering education were developed and both concepts were translated to research instruments for testing. The research instruments were designed into two shapes, one in ranking task (quantitative approach) and another one in reflecting task (qualitative approach). The ranking task instrument was designed to identify sustainability experts´ stance on concepts of sustainability in engineering education, whereas the reflecting task was designed to understand experts´ justification on the concepts of sustainability in engineering education. Fig. 2 depicts the exploratory mixed methods design that used to address research problem (iv) and executed in the phase one of overall research model.

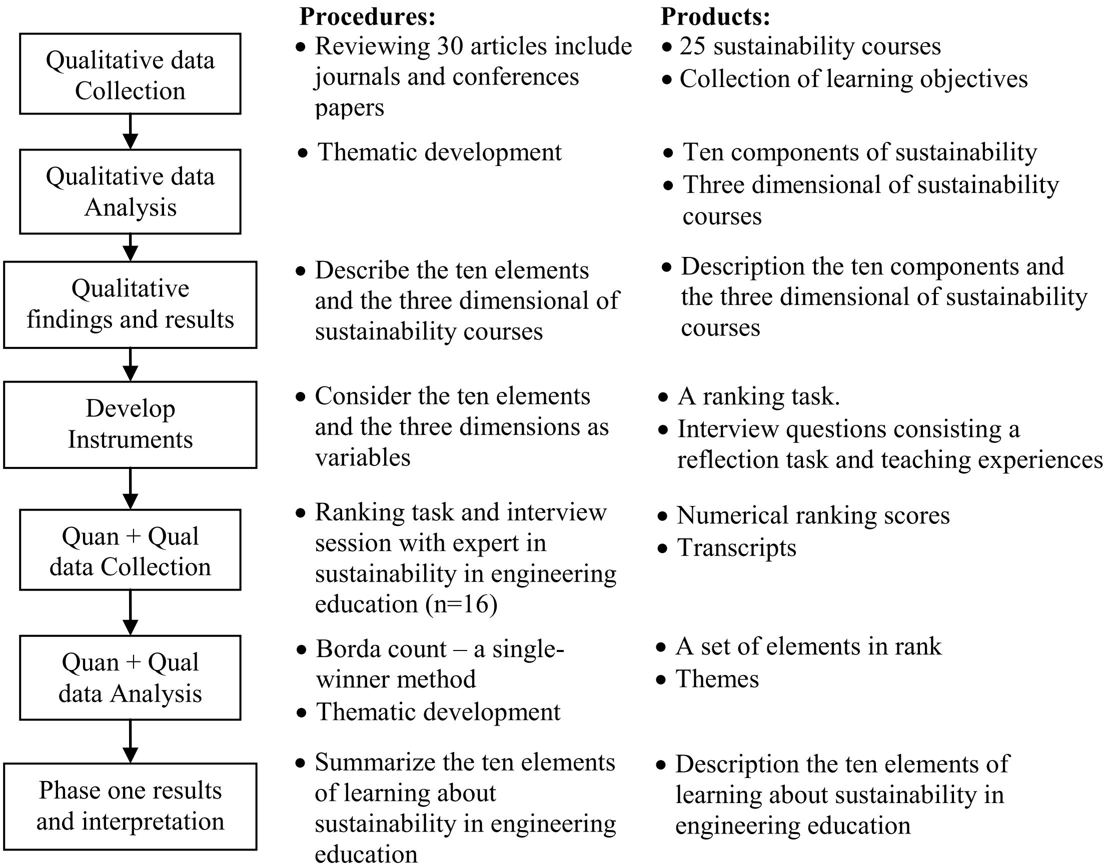

Fig. 2. Phase one - mixed methods design

3.3 Phase two: Excerpting positive practices

In the second phase, this study is using qualitative approach in addressing research problems iii, iv and v. The study divided into two cases, the first case study was at Universiti Teknologi Malaysia and the second case will be at Aalborg Universitet. Both cases were selected to represent a wide range of engineering programs and sustainability courses, a variety of pedagogical strategies and the results from both cases will complementing to one and another. The qualitative data began with reviewing engineering programs offered at both universities either in undergraduate programs or postgraduate programs. Results from extensive qualitative data analyses and participation agreements from the Universiti Teknologi Malaysia, seven sustainability courses were met a point to be further study in-depth. In order to have a smooth session of collecting data, preparation of the research instruments are important and made upfront agreements with prospective university including every level of organisation, Dean of school, Head of Department, Course Coordinator and teachers. Fig. 3 shows qualitative research design in the phase two.

3.3.1 Data collection process

The first case study was endured for three months which commenced from 20th February 2012 until 19th May 2012. The collections of data started off by inventorying the programs offered in Universiti Teknologi Malaysia. Eight programs were identified based on the courses with characteristics of sustainability courses and validated by course coordinators through feedback on a course inventory. Fig. 4 depicts the qualitative data collection process.

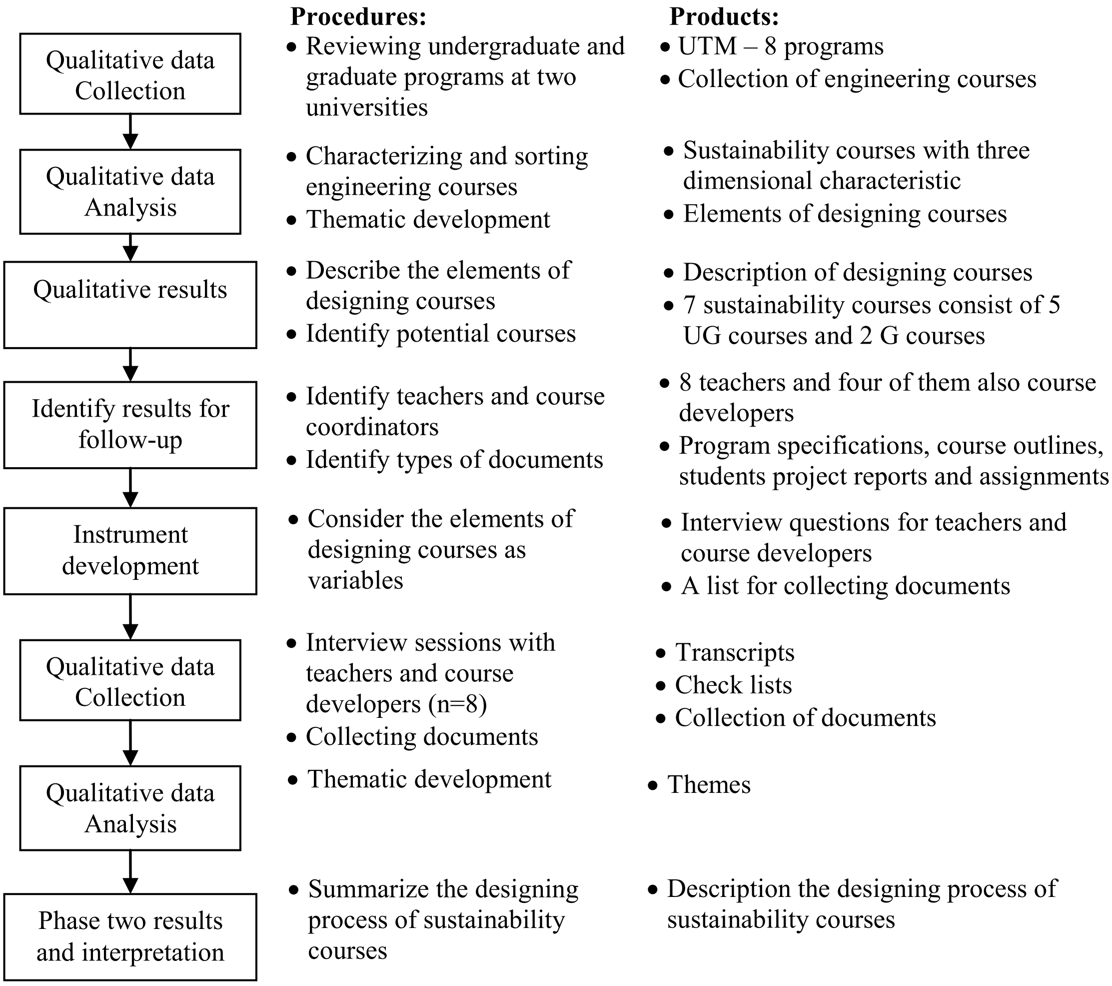

Fig. 3. Phase two – qualitative design

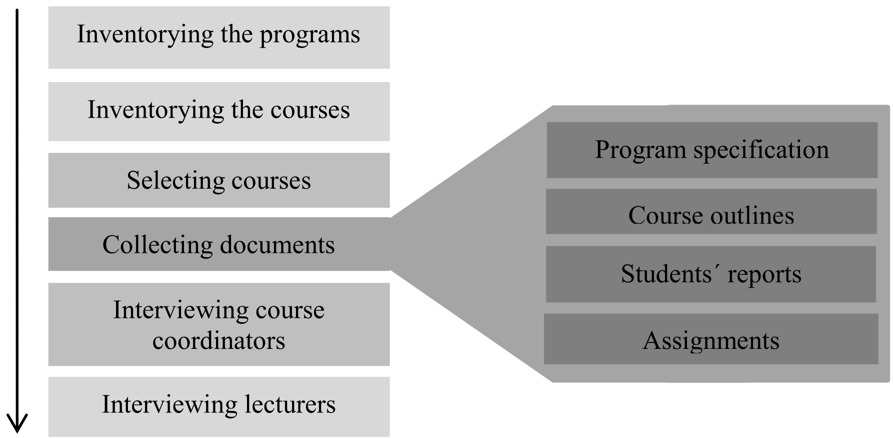

Fig. 4. Qualitative data collection process

Each of the selected courses were studied in-depth in term of the course development strategies, teachers' experiences of teaching sustainability in engineering education and students´ understandings of learning sustainability. As the first steps of in-depth study, document analyses were administered to the collection of course outlines, students´ reports and assignments. The strategies of course development in the perspectives of educational philosophy and pragmatic point of views were also clarified during the interview sessions with course coordinators.

The following Fig. 5 shows the research model of the case studies, demonstrates from the left to the right, the alignment of three components consist of research variables, data collection techniques and expected research outcomes. The upper part of the research model shows how the research lead to the development of framework for designing sustainability courses while the lower part shows how the study will develop evaluation tools and indicator for sustainability in engineering education.

A study on the teaching and learning of sustainability in engineering education has provided reliable information and trusted data. Teachers and course coordinators were two groups of experts that deemed essentials in understanding the strategy to design curricula that had been taken by the universities. For instances, qualitative data such as teachers´ experiences on teaching sustainability courses and course coordinators´ design experiences are highly significant to the study. These data also provide important elements to the development of main structures for designing a framework of sustainability courses in the perspective of pragmatism.

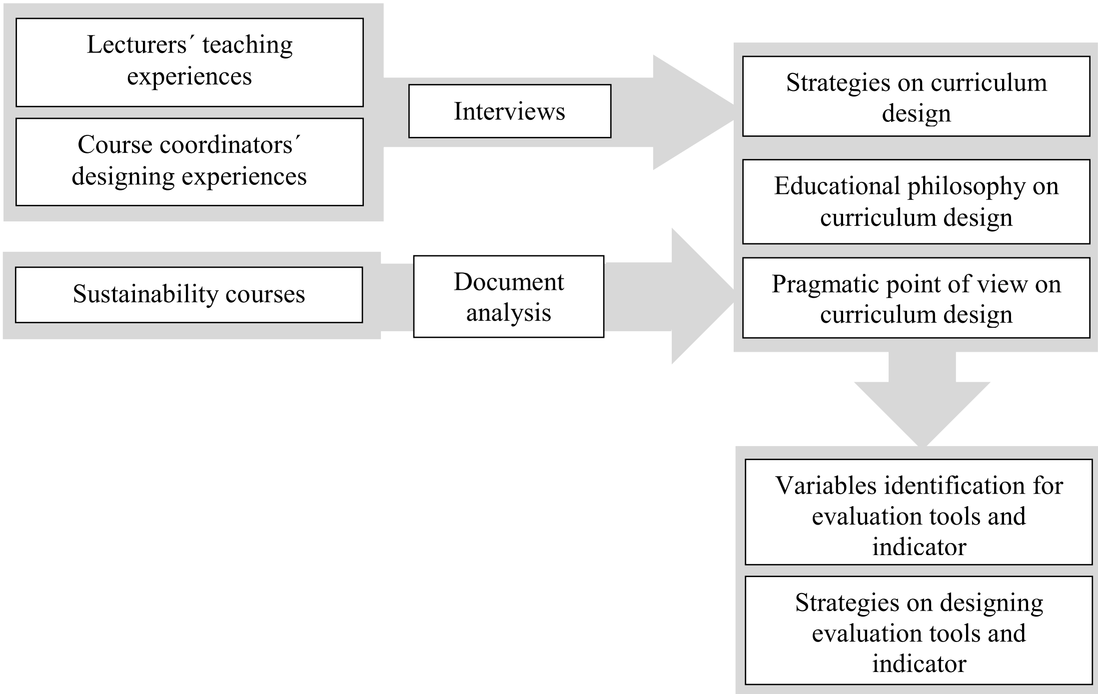

Fig. 5. Research model for case studies

3.4 Phase three: Evaluating course effectiveness

In a basic design cycle, evaluation is the final process that sort out the effective and the ineffective of the design. Basically there are two approaches of evaluation, a product evaluation and a process evaluation. In a curriculum design, formative and summative evaluations are possible form of evaluations can be applied for evaluating the curriculum. Evaluating the course effectiveness requires indicator to determine the effectiveness of a sustainability course. The indicator has to be developed based on concepts and principles of sustainability.

As a question on, how effectiveness of the course can be measured? For this purpose, this study has defined the effectiveness of the sustainability courses from the capability to provide a sufficient requirement for achieving targets or goals. In practice, the targets or goals of the course can be identified by the learning objectives outline by the course developer. Therefore, as illustrate in Fig. 6, the capability of the course to provide the sufficient requirement can be measured by evaluating the students learning outcomes and comparing it to the learning objectives. For this purpose, researcher has categorized students´ learning outcomes into three elements, knowledge, skills and attitudes.

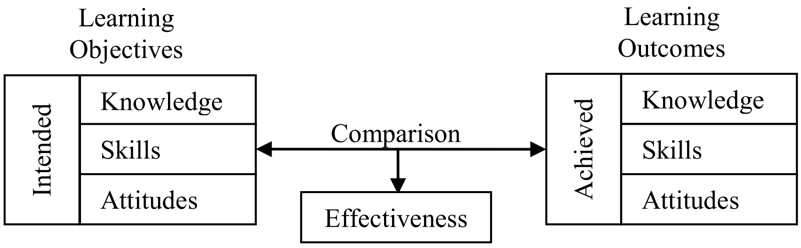

Fig. 6. Strategy of evaluating courses effectiveness

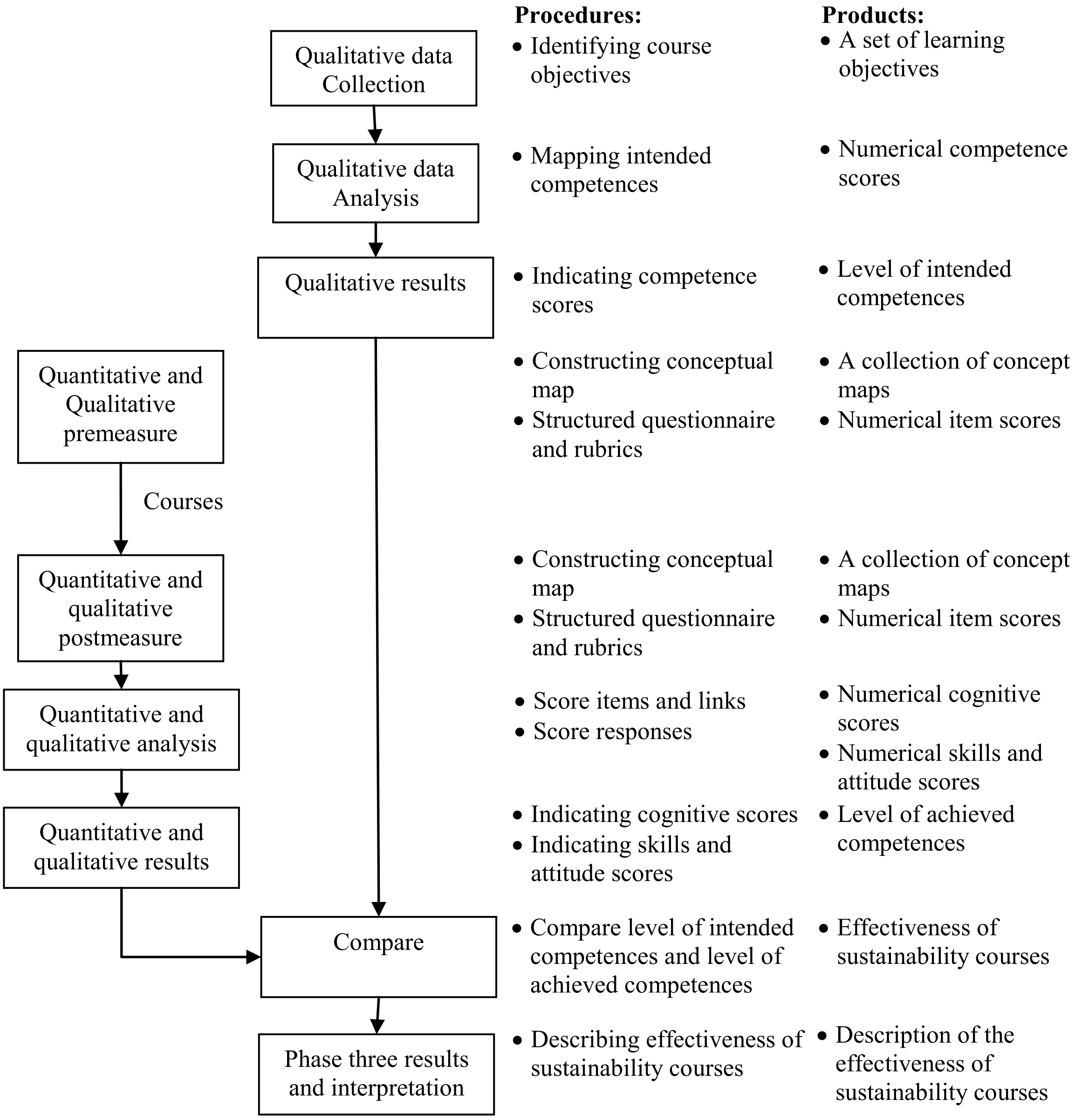

Fig. 7. Phase three – mixed methods design

The mixed methods design for phase three will address all research problems which mentioned earlier in this paper. A triangulation mixed method design will be used as the main design for evaluating students learning outcomes, on the other hand qualitative design will be used to evaluate learning objectives. Qualitative data such as skills and attitude competences will be evaluated quantitatively through rubrics scale while cognitive competences will be evaluated qualitatively through conceptual maps [4 - 7]. Fig. 7 demonstrates procedures and expected products in the phase three mixed methods design.

3.5 Phase four: Validating design framework

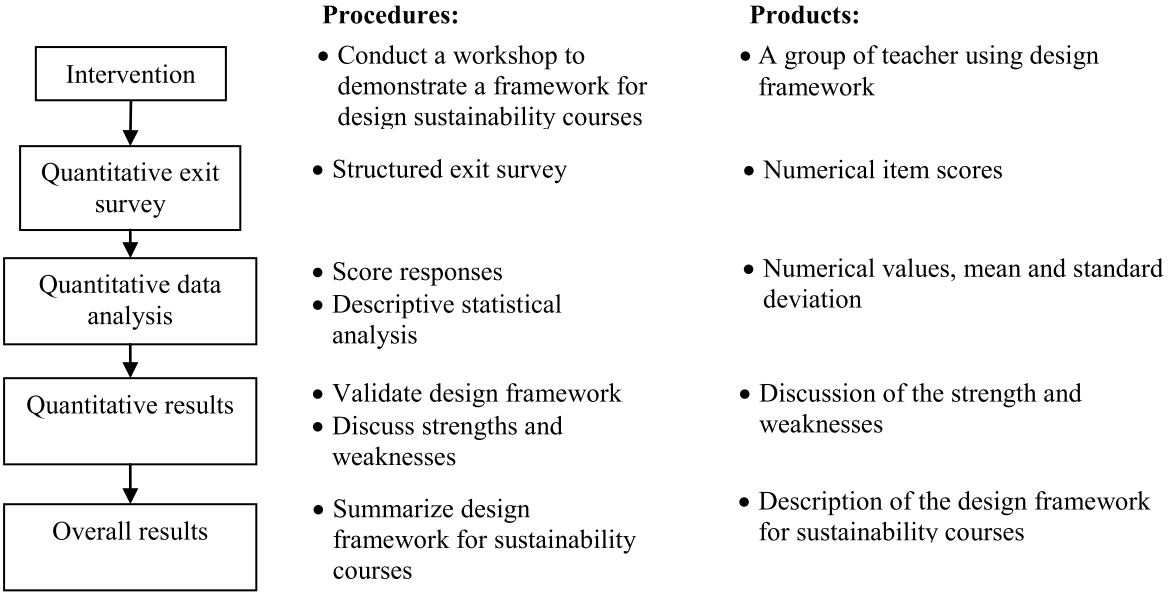

Fig. 8. Phase four – pre-experimental design

The final phase of this study is to validate a design framework as depicted in Fig. 8. The framework will be presented to a group of teachers in a workshop for developing a sustainability course. In this workshop, the teachers will use the framework and working together with facilitators to see how the framework works. A structured exit survey will be distributed to the participants to obtain feedbacks in term of the strengths and the weaknesses of using the framework for designing sustainability course.

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Integrating Sustainability in a PBL Environment for Electronics Engineering

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Abstract

In the past decades, education for sustainable development (ESD) has obtained increasing recognition as a general subject in higher education (HE). Institutions worldwide have had attention to the integration of sustainability into the curricula, and on the conceptual level problem based learning (PBL) has been put forward as a promising pedagogical model and emerged as an opportunity to implement sustainability successfully. Due to the almost forty years of experience in PBL, a case study was carried out at Aalborg University, Denmark to excerpt their experience of integrating sustainability in a problem based learning environment. Three electronics engineering project modules were selected as example and empirically supported by constructed interviews with staff and document analysis of selected material. The findings were analysed with a systems approach and presented with reference to three difference factors: input, throughput and output factors; whereas reflections on the study is presented in the final part. It is found that the PBL practices in the modules comprehend the integration of sustainability in engineering education without compensating technical and engineering competencies as the core contents.

Keywords: Sustainability in Engineering Education; Education for Sustainable Development; Problem based learning;

1. Introduction

In Denmark, problem based learning was founded in the early 1970s by institutionalizing the problem and project pedagogies in two universities, Roskilde University Centre in 1972 and Aalborg University in 1974 (de Graaff and Kolmos, 2007). Learning by doing and experimental learning were two of the central principles (de Graaff and Kolmos, 2007), and the students were to work in collaboration with teachers and others to explore and solve a problem in close relation to the social reality in which it exists (Berthelsen et al., 1977). Thereby, the societal context was a key consideration from the very beginning, drawing from (Mills, 1959) among others and his visions of social imagination.

As such the path to integrate sustainability was established, but it was not before the Brundtland Commission, chaired by Gro Harlem Brundtland, published their famous report “Our common future” (Brundtland Commission, 1987) in the late 1980s that a sustainability discourse was developing at the Aalborg campus. In the 1990s sustainability started to show explicitly in curricula. One of the more comprehensive initiatives were taken by the former study director Mona Dahms, being responsible for a gathered first year of all educational programs at the Faculty of Engineering and Science. In this first year, students were working in inter-disciplinary groups on projects for sustainability. This example still stands as the most throughout integration of sustainability at AAU. Today sustainability is integrated as a patchwork of practices across faculty, whereas management is now determined to gather and develop these practices in order to secure ESD in all programmes.

In this paper, we present a piece of this patchwork of practices at the Faculty of Engineering and Science Aalborg University, to exemplify the integration of sustainability in a problem based learning environment. The case study example is related to engineering education and more specifically electronics, and has been designed as a complimentary data which part of the research were executed at Universiti Teknologi Malaysia, Malaysia. In the

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following we elaborate on the case, the methodology and the results, whereas we in the concluding part point to reflection that can be of general interests for institutions working with ESD in a PBL environment.

2. Case description – three project modules in electronics and IT

In this paper, three project modules are presented as an example of progression of ESD practices in the Study programme of Electronics and IT. The project modules are offered for first year student in the first semester and second semester and structured as Problem and Project based Learning activities. Typically, the phases of a project module are that the students, within the frame of a pre-defined project unit theme, formulate an initiating problem (sometimes based on a catalogue of project proposals), then they move to problem analysis and based on that they formulate a narrower problem within pre-defined disciplinary boundaries. Taking the point of departure in this problem formulation and a methodological framework, they solve this problem and assess the proposed solution taking results of the problem analysis into consideration.

In this case the three project modules are as follows:

A. Technological project work (P0 - approx. 5 weeks)

This module is offered to provide students with an insight in a problem based learning environment and at the same time introduce basic concepts and applications in electronics and IT. The problem presented here is rather narrow within a technical frame of mind.

B. Basic Electronic Systems (P1- approx. 10 weeks)

This module is structured to provide a platform for enabling students to be socialized into the electronics and IT-related engineering disciplines. Theoretical and practical work is combined, taking point of departure in a problem derived from a community or business context. This problem will be analysed by decomposing the problem in sub-problems in order to select and formulate a technical problem that can be solved by using the theories and methods of microprocessor-based systems. The solution has to be an electronic system, incorporating a programmable computer and being able to react to and/or control parts of its outside environment via selected actuators and sensors.

C. Dynamic Electronic Systems (P2)

In this course students will be through theoretical as well as practical work, based on a selected problem that will acquire knowledge within the electronic and IT related engineering discipline. However, here the students also have to use relevant methods within the field of Science, Technology and Society (STS), that demonstrate that they can contextualize a technical problem including relevant social contexts. Again, the problem will be analysed through decomposition into sub-problems, but in this case the context of the problem in analysed more in depth, which have implication on the formulation of the technical problem. In any case this technical problem has to be solved using electronic systems interacting with the surrounding environment. The final solution will then be evaluated at the end based on evaluation criteria's derived from the technical as well as the contextual analysis.

3. Methodology

In their works, Rompelman and de Graaff have presented the possibilities to analyse the existing world and synthesize `a new world´ with a systems approach, and they also have explored the concept of system approach in an educational context (Rompelman and de Graaff, 2006). The systems approach in this paper categorizes students in the centre of the teaching and learning process. Whereby, the other variables such as course contents are categorized as input factors; abilities, knowledge and skills are considered as output factors; and facilitation and teaching are considered as throughput factors. The reflections on the whole process are then seen as a feedback to re-design the system, see figure 1.

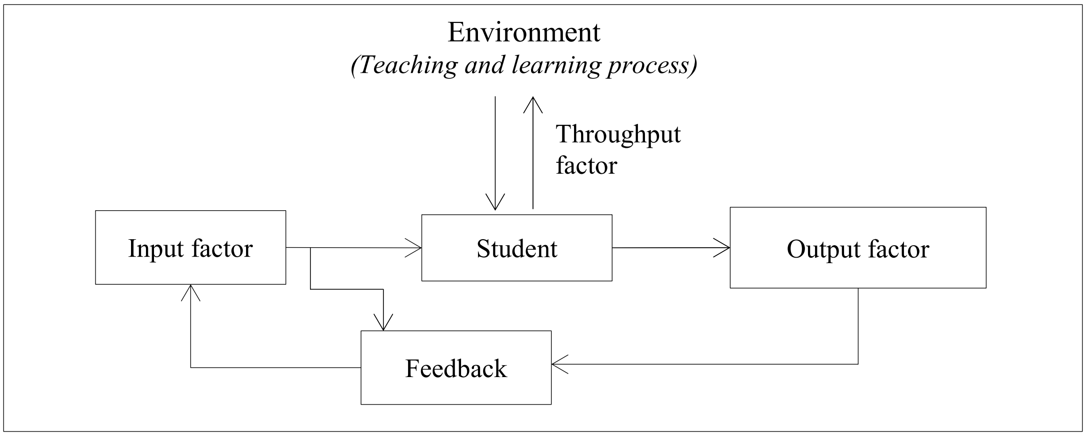

Figure 1. A systems approach for analysing engineering curricula

In the same paradigm, Creemers and Scheerens have used an input-process-output approach, rather specific termed as a context-input-process-output based approach in educational effectiveness research (Creemers and Scheerens, 1994). The system approach in their study instead seem to put the educations in the centre, as the inputs are considered to be students´ background including personal and financial resources, the context is related to educational contexts of schools and socio-economic context, the process or throughput are considered to be the factors within the school, and the outputs are students´ achievements and educational attainment.

In this paper, we lean towards the system approach introduced by (Rompelman and de Graaff, 2006) as the focus is on the educational practice, all though inspired by (Creemers and Scheerens, 1994) to take into consideration broader institutional input factors. Two main data collection techniques were used for this analysis: document analysis and interview sessions. First of all, documented evidence such as electronic and electrical engineering curricula, course/module outlines, students´ assignments and students´ project reports was collected. The key words related ESD (i.e. sustainable development, sustainability, environmental perspective, social/culture perspectives, sustainable technology, green technology) were used to identify the manifestation of the integration in the document analysis. Secondly, four interviews were planned and carried out with teachers, coordinators of the modules and ESD experts. The data were collected from September to December 2012. The interview sessions were structured to identify intangible forms of integration yet not documented and beyond what could be read in the available documents.

4. Results - Factors of integration

In the following we will present three salient "factors" to analyse the way sustainability has been integrated in the programmes of Electronics and IT. Together with the Danish qualification framework, the written statements in the curriculum related to the three project modules in focus, constitutes the input factors. As throughput factors we consider formulation of objectives/requirements, facilitation and team activities during the project period, and finally as output factor, we have considered students learning outcomes represented by project reports.

4.1. Input factors

Input factors are considered as the input for the students in the teaching and learning process environment. The input consisting of all kind of variables related to the structure of program i.e. the electronic and electrical engineering curricula and courses/modules outlines and teaching materials. Besides that, the institutional context of the program structure is also considered as an important input factor, here represented by the Danish qualifications framework.

4.1.1. Documented in Danish qualifications framework

The Danish qualifications framework aims to make the degree structure in Denmark for higher education programs nationally and internationally clarified and transparent. The qualifications framework also describes the desired outcomes and competencies in such a way that it can steer curricula planning. The importance of the qualifications framework is underlined by the inclusion of stakeholders representing universities, non-university programs, students, Danish Evaluation Institute, Danish Centre for Assessment of Foreign Qualifications and employers.

In general, the Danish qualification framework was established based on a model that encompasses 1) Competency profiles, 2) Competency goals and 3) Formal aspects. The competence profiles are provided to specify the variety of competencies needed and three types of competencies are defined being i) intellectual, ii) professional and academic and iii) practical.

Intellectual competencies point to general process competencies for intellectual development; being neither specified as disciplinary nor program oriented, e.g. communications skills, self-learning, analytical and abstract thinking (The Danish Bologna follow up group's QF working party, 2003). By this time on the Bachelor level, students have to be able to identify their own learning needs and organise their own learning in different learning environments (Ministry for Science, Technology and Innovation, 2009). This goes well together with PBL and its emphasis on exemplary learning as well as meta-learning.

On the contrary professional and academic competencies are related to a specific discipline or programmes, whereas practical competencies are specifically aimed to the fulfilment of job functions e.g. professional ethics and responsibility (The Danish Bologna follow up group's QF working party, 2003). Even at the bachelor level, the qualification framework state that engineering students must be able to handle complex and development-oriented situations in study or work contexts, and furthermore that they must be able to independently participate in discipline-specific as well as interdisciplinary collaboration with a professional approach (Ministry for Science, Technology and Innovation, 2009). Taking the increasing complexity of technological systems into considerations as well as the increasing focus on environmental management and corporate social responsibility in business, the qualification framework creates an important platform for integrating sustainability in engineering education.

4.1.2. Sustainability related learning objectives in the written curricula for the three modules

All though the Danish Qualification framework provides a platform for integrating sustainability it is not a premise for accreditation that sustainability is explicitly mentioned in the written curricula. This is however the case for the curricula for electronics in relation to the first year as shown in the analysis of the learning objectives, related to the following three project modules.

In the project module entitled Technological project work (P0), the overall objective enables students to describe and apply typical elements of a problem-based project, manage the learning process and provide reflections on this process. The relation to ESD is that the students should be enabled to describe the problem in a holistic perspective.

In the following project module, Basic Electronic System (P1), the course learning outcomes were constructed to provide students with knowledge, skills and competencies related to both electronic system and ESD. At the end of the course, students is expected to understand the basics of electronic systems, but this also includes interaction with the outside world and identification of relevant contextual perspectives including technological as well as societal aspects. The students is also expected to identify requirements for technical solutions based on these contextual perspectives, and furthermore show their ability to manage a project include planning, structuring, implementation and evaluation. In addition, it is stressed that the students have to take point of departure in a problem having societal or vocational relevance.

The last project module on the first year, Dynamic Electronic Systems (P2) is offered at the second semester for electronic engineering students. The module is, besides progress in the understanding of electronic systems, specifically designed to integrate knowledge related to the field of Science, Technology and Society (STS) supported by a subject at the first semester. Students have to obtain adequate skills to analyse and solve a technical-scientific problem taking technological, environmental and also social aspects into consideration in the problem analysis as well as in the assessment of the social and environmental consequences of the proposed solution. Specifically user involvement, stakeholder analysis and analysis of environment regulations are mentioned as areas of interest. In the process of solving the problem, students also have to sharpen their abilities to construct comprehensive models to be used in design, implementation and test of an overall system to assure that the requirements and the desired specifications are met.

4.1.3. Project proposals

As a third input factor, the facilitators provide students with project proposals designed to the learning objectives in the curricula. It is however possible for students to contribute themselves with a project proposal. Project proposals outline the problem-field and the related possibilities to contextualise and develop technical competence within this field. In most practices, the project proposals are constructed in an open way, so the students themselves are formulating the initiating problem and problem formulation.

This input factor could be the most vital element for the efforts to provide education about sustainability in electronic engineering education, as previously highlighted in the introduction, sustainability could in fact be an overarching theme and the project proposals could be developed to capture different aspects of sustainability in relation to the disciplinary field of work. For instance, there was a P1 project, executed by the second semester of electronics engineering students and the project was designed to deal with pupils with disabilities.

In the electronic and IT programme, the proposal can be entirely funded by industries or companies, or the proposal can be prepared specifically for education purposes. Teachers will normally prepare the proposal and present it among a committee or peers including all teaching staff at the semester. The approved proposal will be collected and offered to the students to choose. The students are thereby occasionally triggered with a proposal in relation to sustainability.

4.2. Throughput factors

In the following analysis the throughput factors are analysed in two sections related to i) the student directed team work and ii) the influence by teachers in the facilitation of students´ project work by questioning students, discussions at group/class meetings as well as feedback to students on their writings. These teacher behavioural factors are positively related with student achievement (Brophy and Good, 1986).

4.2.1. Project activities

Throughput factors in terms of project activities have considerable impact on the integration of sustainability in electronic engineering curriculum to maintain the momentum and manifest ESD as a process and not only an input or outputs of engineering projects. The study has identified three possible activities along the process of developing the project or finding a solution that integrates sustainability, that is i) the identification and analysis of problems, ii) product design and test iii) product evaluation.

Early in the process of identifying problems, the students' start out with an open problem and the further analysis of the problem include an explicit focus on the social as well as environmental aspects of the problem. Some of the problems, either proposed by the teacher or students, demand at least a site visit and discussions with stakeholders. During such processes, students will have opportunities to identify related issues regarding the technical problems as well as the related non-technical social and environmental aspects. They also have to develop instruments for collecting data such as interview guidelines and questions for interview sessions with the stakeholders; and in the design of these instruments an explicit focus on sustainability is evident.

Later in the process of designing the possible solution to the now well-defined problem, a specification of the demands to the products can be made based on the conclusion of the problem analysis. All though students often delimit the project by a narrow problem formulation calling for pure technical developments – the students then are aware of the more contextual factors coming into play in real life product development, where departments of environmental and/or health and safety often are involved. In that way they learn how to be specialist in a team and at the same time have enough inter-disciplinary knowledge from cross-departmental collaboration.

In the same line of reasoning, students are, in the last part of the project, asked to make overall assessment of the products impacts on environment as well as society at large. In this phase more strategic management tools as SWOT analysis (assessing the strengths, weaknesses, opportunities and threats) or screening tools (e.g. in relation to environmental assessments) often are in play.

4.2.2. Facilitation

One of the cardinal features of PBL is that the students are at the centre of the learning process, and have to take responsibility for their own learning. The teacher is not telling students what to do, but instead guide them along the process of learning with reference to the learning objectives. Unlike the traditional methods of learning, where teachers usually has full control of learning process and contents, teachers in a PBL environment takes the role as facilitator (Kolmos et al., 2008).

The role of facilitator in a PBL environment is to keep students on track in their projects, so they progress in alignment with the intended learning outcomes. Therefor for the facilitator to make sure that sustainability is integrated in the project work, there have to be a clear reference to the curricula. On the other hand, if the learning objectives do not point to the integration of sustainability, this sometimes unintentionally occurs in the process, due to nature of the chosen problem, which is closely related to the field of interest of students. Based on the learning objectives or student's interest, the facilitator will provide some insight and maybe put some more emphasis on sustainability in the project facilitation.

However, the integration of sustainability challenge the facilitators to have a clear understanding of the subject and as one of the criteria's for accreditation of HE in Denmark is that the teaching has to be research based, this calls for an inter-disciplinary team of teachers. In this specific case, teachers from the Department of Development and Planning contribute with researchers working in the field of sustainability science and Science, Technology and Society (STS). These researchers are involved in a course module at the first semester, and co-supervise the groups in the project module in the second semester.

In the case where sustainability is integrated in the project modules, the facilitators play important roles in motivating the students and help students to open up to other lines of thinking. This sometimes happens, when the facilitators question the conditions of the project or provide suggestions to integrate economic, social or environmental concerns. This often leads to discussions of the role of sustainability in the project and the ways to integrate sustainability in the project without compensating technical competences. This directive approach (with reference to the learning objectives in the study regulations) combined with a collaborative approach is very much depended on students´ motivation, performances and ability to achieve the course learning objectives.

In other cases, students had opportunities to meet external personnel such as engineers and managers from companies to make a network and collaboration on developing their projects. To get in contact with various stakeholders and meet with the target groups or users of the products was a great experience for students to understand their problems and to develop their project. In this way students also have the opportunity to experience, that sustainability plays a role in real life innovation of electronic products.

4.3. Output factors

In a systemic approach, output factors of teaching and learning process are referred to the students´ learning outcomes such as basic skills, other cognitive outcomes and non-cognitive measures (Centra and Potter, 1980) or abilities, knowledge, skills and competences (Rompelman and de Graaff, 2006). In this paper, it is assumed that students´ project report can be analysed as representations of students learning outcomes. Six reports are analysed, two from each module, to exemplify the progression in the integration of sustainability in the first semester of study (P0 and P1) and in the second semester of study (P2).

4.3.1. Students' reports in P0 – getting a sense of electronics and PBL

The analysis of two P0 reports showed that the students have reached the intended learning objectives in relation to PBL and basic knowledge in the field of electronics. The students all had the same project proposal, where they had to develop a robot by use of LEGO mindstorms® (see example in figure 2), that was able to cope with some challenges put forward by the facilitators e.g. carrying items or follow a predefined route. Being able to build something and enter into competitions with each other motivated the groups. However, due to the very fixed technical challenge, it is very hard to find any evidence that the students in fact have had a holistic perspective on their project as intended in the learning objectives.

4.3.2. Students' reports in P1 – the social responsibility project

In the P1 project reports, sustainability solutions are the target, but at the same time reflections or relations to sustainability are not explicit in the report.

Figure 2. Stimulation of sight and hearing-handicapped

In one project, students proposed stimulation tools for pupils with sight and hearing disabilities. Due to pupils´ disabilities, it is vital that the tools have cardinal features such as interaction and strong responses to the user. The strong responses could be in the form of light, sound and vibration. In addition to that the students have to present ideas of activities that combine physical activity with social elements and learning to stimulate the pupils at Centre for Deaf blindness and Hearing Loss, CDH. The project also included i) A study of possibilities for stimulating sight and hearing disabilities based on interviews with employees at CDH and selection of ideas to project development, ii) Preparation of technical specifications for the system iii) Design and construction of a laboratory model, and iv) A testing and assessment product.

The other project considers assistive technology for people with sight disabilities in order for them to manage everyday life. In the project, the students made interviews with representatives from the Danish society for the sight disabled, to point to the most important challenges in the everyday life of blind people, get an overview of the assistive tool already at hand and what demand they this organisation have for assistive technology. Based on that, an interface instrument was developed to help blind people in their use of public transport.

By focusing on the assistive technology, these two projects can be considered as social responsible projects. Furthermore, the real life social problem is carefully analysed by involving the target group and use their input for product design. However, there is no explicit reference to aspects of economic or environmental sustainability; and there is no real trace of sustainability in the approach to the problem analysis and problem solving.

4.3.3. Students' reports in P2 – integration of sustainability

Students report at P2 is clearly influence by the increased and more specific integration of sustainability in the learning objectives and the presence of a co-supervisor with special attention and competences in relation to STS and ESD.

Figure 3. Intelligent headphones

In one of the reports social sustainability play a role in the purpose of the project that is to improve traffic safety by intelligent headphones identifying and amplifying signals of danger. Other projects working with intelligent headphones have instead been targeted at the quality of working environments by reducing noise problems. This is an example of the same product type and basically the same technical learning outcomes related to different types of problems related to different contexts. In the analysis of traffic safety problems the students draw open statistics of traffic accidents and they develop a survey instrument to investigate different types of distraction problems in traffic. Furthermore students measured the amount of noise in traffic and developed a prototype. In the final part of the project, they made overall assessments of the environmental impact from the hardware and estimated the market price.

The other report analysed from P2 have the objective of making a small satellite, which can be used for educational purposes at high school level. Interviews are made with high school teachers and pupils in order to develop an educational set-up around the satellite. Interestingly, student estimated the environmental impact from the satellites as a part of their problem analysis – and thereby before they develop their prototype. They calculate the CO_2 emissions to send up a satellite and found that the emission of sending up one approx. equals 1.25 km of car driving. Besides environmental regulation is discussed referring to the WEEE directive (on Waste from electrical and electronic equipment) and the RoHS directive (Restriction of Hazardous Substances). Based on these and more technical consideration a prototype of a satellite is developed.

5. Reflections and final remarks – feedback to create new input to ESD

Even though the qualification framework creates an important platform for arguing that sustainability should play a role in HE, it is not a criterion for accreditation that sustainability is explicitly addressed in the curricula. In a PBL environment this is however crucial, as the learning objectives in the curricula is the frame of reference when guiding students in their learning process. However, bottom up initiatives are also important drives e.g. by staff proposing projects with sustainability focus or students choosing to integrate sustainability in their projects.

However, sustainability cannot be prescribed – it has to be lived, and as such be a part of the project activities and facilitation. Interviews with staff together with analysis of students report points to the conclusion that students do need to be facilitated to maintain the focus on sustainability and at the same time find a way to cope with this relatively complex subject in relation to a specific context without compensating core technical competences. Choosing sustainability in relation to the problem field e.g. by assistive technology for hearing disabled, is one way to integrate sustainability, but from this does not necessarily follow and comprehensive and holistic perspective in the design and implementation of the product. On the other hand the ability to make overall assessments of the environmental, economic and social impacts from a technology should be developed at some time in the curricula, and here the strategy at Aalborg University has been to make sure that co-supervision is provided in the field of STS and ESD. Due to the strong collaboration in the supervisor team, this might also be an indirect training of staff and raise the awareness of sustainability in research environments where this is not considered as the core discipline.

Sustainability has to be included and the aims or goals must be aligned in all three factors therefore the sustainability can be effectively addresses along with the teaching and learning process. The cases have showed that the sustainability was partly in the written learning objectives, dedicatedly discourse in the project activities or facilitation and documented in the project reports. However, there is still a room for improvement where the alignment of the three factors needs to be part of overall assessments. So that, the teachers as well as the students have opportunities to reflect and make improvements in any part of the learning process that insufficiently address the sustainability. We also find out that even though students have showed their abilities to reflect their projects in the perspective of sustainability which commonly documented as a part of the project background and end-of-pipe analyses of project. There was a lack of reflection on sustainability perspective along the process of project development or realization.

However the case-example from Aalborg University shows that, it is in fact possible to integrate ESD without compensating technical and engineering competencies as the core contents. This is however due to a very structured project model, where students gradually work from an initiating and very open problem, through a process analysis phase, whereas they have gained a comprehensive understanding of the problem to narrow this problem to a technical problem to be solve, but still being aware of the limitation of their technical perspectives in a business as well as in a broader societal context. Engineers are not necessarily to become environmental managers or sustainability scientists; but they have to know how to bridge and collaborate inter-disciplinarily in their future profession in order to design sustainable sound solutions. We hope that this paper have provided some insight of the possibilities of making our engineering students ready to take on this responsibility.

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Key sustainability themes and competencies for engineering education

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***Abstract**: The emergence of sustainability in engineering education has transformed the engineering curricula in several universities. The education transformation includes the integration of sustainability into existing engineering curricula through various kinds of models, approaches and orientations. These varieties of integration have led to the development of sustainability concepts in engineering education into many ways of implementations and interpretations. Additionally, these varieties can be seen through the discourses of the principles and concepts of sustainable development, and as well as the engineering courses itself. This paper will propose four key sustainability themes and sustainability competencies for engineering education. The paper will conclude with the key sustainability themes that "connecting", "conceptualizing", "valuing" and "implementing" sustainability into engineering education. The paper also will conclude that the implementation of the four themes is able to drive engineering education for sustainable development. Further, it is highlighted that the key sustainability themes and competencies can provide pragmatic perspectives on integrating sustainable development concepts into the existing engineering curricula.*

Introduction

The concept of Sustainable Development (SD) is globally accepted based on the report of the world commission on environment and development, *Our Common Future*, as the ability of humanity *"to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Brundtland, 1987). The concept of SD has been explained further in various studies in order to define the concept for practice. Jabareen (2004) has drawn the concept of SD in a knowledge map and identified seven metaphors that also contribute in constructing the knowledge map. The concept of SD is presented in the ethical paradox metaphor, the natural capital stock metaphor, the fairness metaphor, the integrative management metaphor, the eco-form metaphor and the utopian metaphor.

In other study, the concept SD is basically presented using the sustainability paradigms with regards to very weak sustainability, weak sustainability, strong sustainability and very strong sustainability. Based on these paradigms, the concept of SD is explained further and defined in terms of capital based, such as man-made capital, natural capital, human capital, moral and culture capital (Turner, 2005).

Despite of the continuous debate on its concept and the definition, issues surrounding SD is constantly brought into discussions, framing a new set of principles and practice in engineering. Manion (2002) suggests new values and attitudes for engineers and business-people toward sustainability. He brought up issues such as public policy in engineering profession, arguments between engineering and business management as well as engineering ethics. He suggested that engineers and business-people should value the environment together with the economic development, value future as well as current generations, value social equity as well as material growth and value the poor along with the rich.

Abraham and Nguyen (2003) summarized a four-day conference with a theme *Green Engineering: Sustainable and Environmentally Conscious Engineering*. The conference was held with the aims to develop a set of principle for green engineering by taking into account several principles of green engineering developed in the past. The green engineering is accepted as steering principles of the transformation of engineering fields into sustainability. In the end, the report by these authors drafted nine principles of green engineering.

The concept of SD also has been framed into a discipline where SD has been incorporated into civil engineering (Fenner et al. 2004). The author addressed the complexity, fragments and diverse standpoints of SD and eventually reflects the concept into eight-point framework. In addition, study by Boyle and Coates (2005) developed sustainability principles for engineers based on findings from previous researches. They came up with three key principles, which are (a) maintaining the viability of the planet, (b) providing for equity within and between generations, and (c) solving problems holistically. In Engineers, Society and Sustainability, a lecture series compiled by Bell (2011), the author summed up by pointing out the important role of engineers in handling conflicts between the values of society, clients, environment and technology.

Besides the acceptance of the SD concepts in engineering context, either in practice or in scientific discussions, the importance of SD concepts for engineering education also has been discussed in the world of academia. For instance, the Declaration of Barcelona is the manifestation of debates in the second International Conference for Engineering Education in Sustainable Development. The declaration underlines seven attributes for engineers, which include technological aspects, environmental aspects and social aspects (Declaration of Barcelona 2004). The development of principles and guides for SD in engineering education also has been carried out by The Royal Academy of Engineering. The institution outlined their findings with a set of twelve guiding principles to conceptualize the SD concept into teaching and learning in engineering education (Dodds and Venables, 2005). In other study by Taoussanidis and Antoniadou (2006), the authors were reasoning the importance of sustainability in engineering education and discussed the challenges for engineering faculties. In addition, they were also contextualizing the SD concepts into engineering skills.

Methods

This paper outlines sustainability competencies that are derived from an inductive analysis of the SD concepts and principles. This also includes the contextual concepts of SD in engineering as well as in engineering education. Nine studies and two documented reports were studied. The selection of the studies and reports was based on two criteria. First, the discourse of SD is presented in the perspective of engineering as a profession or field and second, the SD concepts are discussed in three major aspects (environmental, economic and social aspects). The SD elements were identified from the common elements that can be found in the principles and the concepts presented; e.g. environmental assessments, social rights/value, equity and holistic approach/systemic approach. Through this analysis, the properties of the key sustainability themes have successfully been constructed and provide sufficient descriptions.

The method used in the inductive analysis was then flipped in order to map the sustainability competencies from the nine studies and two documented reports. This is where the deductive analysis technique came through. The common elements also were used as a framework in identifying the competencies offered in the sustainability courses, based on 15 published articles and 10 documented course outlines. A total of 118 learning objectives were used for this analysis. This analysis provides more contextual aspects of the themes properties and correlates common elements into engineering education.

In addition, a questionnaire instrument has been developed based on the framework and further refined so that it will also suitable for interview sessions with teachers and experts. The interview participants were 17 teachers and experts in the field of sustainability in engineering programs from two universities (Universiti Teknologi Malaysia and Aalborg Universitet) and five more participants from other institutions.

Featuring sustainability themes and competencies

Table 1 shows the result from the inductive analysis of the eleven concepts and principles of SD, which were described earlier in the introduction part of this paper. Two of the studies had a discourse of SD in general context, five studies focused on engineering and the other three studies focused on engineering education. Table 1 also shows the result from the deductive analysis of 25 engineering courses that related to sustainability. The stated learning objectives/learning outcomes were analyzed based on the elements of SD.

Table 1: The analysis of the SD principles and concepts and course learning objectives

	Elements of sustainability in engineering																
	Fundamental knowledge of sustainability	Ethics/moral	Empowerment of engineer	Environmental management	Environmental assessments	Resources	Social rights/value	Citizenry	Equity	Culture	Quality in engineering	Green or ecology technology	Holistic approach/ integrative approach	Stakeholders	Global	Local	Economic
No of studies (/11)	4	8	1	7	6	6	7	3	5	6	3	4	9	5	3	3	1
No of courses (/25)	13	3	6	5	9	5	7	1	0	0	3	8	4	1	7	8	6

Key sustainability themes and competencies

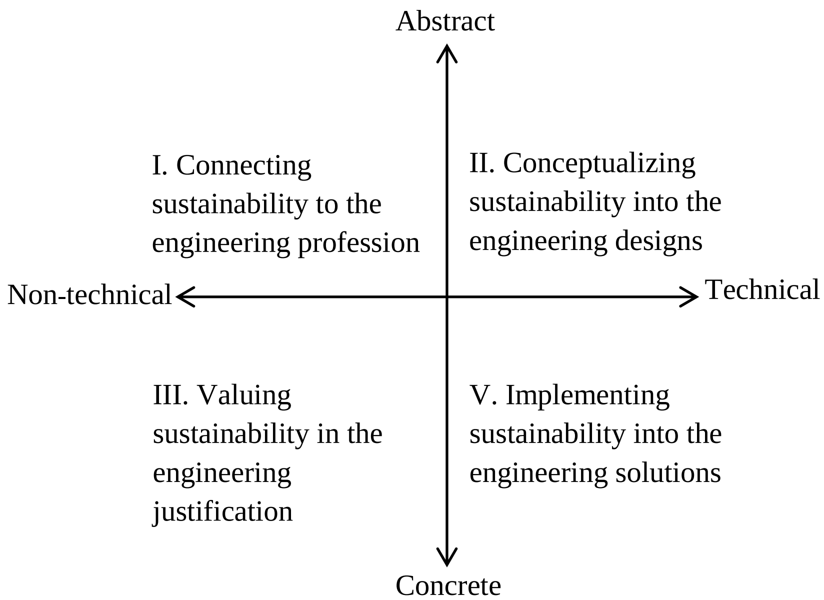

Figure 1: The key sustainability themes for engineering education

Integrating the broad concept of sustainability into the existing engineering curricula is a very challenging process. The contents of the three pillars, environmental, economic, and social, are too broad to fit into a single engineering course or numbers of engineering courses. Despite these challenges, changes have to be done. Key sustainability themes can be a useful method to integrate the three pillars into the existing engineering curricula. The sustainability themes are proposed without intention to narrow down the concept of sustainability; however, it is an effort to put the concept into a visualize representations appropriate for engineering education. There are four key sustainability themes which are illustrated in the Figure 1.

Theme I, Connecting sustainability to the engineering profession

Theme I encompasses the elements of sustainability which are the fundamental knowledge of sustainability, the engineering ethics/moral, the empowerment of engineer, the global issues and the local issues. These sustainability elements that focus on non-technical contexts and abstract concepts are commonly integrated in engineering education as an introduction for engineering students to view the concepts of sustainability. The Theme I contains the elements that are a basic knowledge, principles, concepts and issues that give a general picture of SD. These elements are important information for students to understand SD concepts and we believed by connecting SD into the engineering profession, the students could increase their understanding and eventually they have a strong foundation on SD concepts.

Theme I – Sustainability competencies

The attributes of engineer in acquiring the fundamental concepts of sustainability can be seen in the Declaration of Barcelona where engineering students are expected to *"participate actively in the discussion and definition of economic, social and technological policies…"* (Barcelona Declaration, 2004). The basic concepts of sustainability, such as the concepts of social, cultural and environmental should be understood precisely, so that engineers not only use their technical training as solely way of creating solutions but also will be able to provide sustainable solutions rather than traditional technical solutions (Taoussanidis and Antoniadou, 2006). The engineering students are also expected to *"understand the impact of professional engineering solutions in societal and environmental context and demonstrate knowledge of and need for sustainable development"* (International Engineering Alliances, 2009). A study by Jabareen (2004) showed that SD has been developed around ethical concerns, which are, in this context suitable to be integrated in engineering profession. The ethical concerns in SD are debated to the extent that, *"Individual wants (preferences) have to be distinguished from needs. For humanistic and institutional economists, individuals do not face choices over a flat plane of substitutable wants, but a hierarchy need…. Sustainability imperatives, therefore, represent high-order needs and values,"* (Turner, 2005). This attribute, the engineering ethics, has been discussed in various studies where ethical concerns are highlighted as a crucial attribute for engineering profession in achieving sustainability. As the discussions on the importance of ethical concerns in SD continues, a future engineer with abilities to apply ethical principles and to commit to the engineering ethics are stated as the attributes for professional engineers in the international engineering alliances in 2009 and outlined in Barcelona Declaration earlier in 2004.

Other two elements of sustainability that suggested in the theme I are the global and local issues. In our findings, the teachers perceived that sustainability has to be framed into local context, which *"local problems were more close to students. Students were hardly to appreciate problems that unrelated to them"* (Teacher5). In addition, the teacher added *"engineer should think global for local – in engineering practice, most of the international standards are use in local context"* (Teacher5). Their perspectives on SD in fact in line with one of the principles of green engineering, results from the Sandestin Conference in 2003, *"Develop and apply engineering solutions, while being cognizant of local geography,…"* (Abraham and Nguyen, 2003). On the other hand, some of the teachers focused primarily on global issues, which for them helps engineers to define their profession and responsibilities. The teachers perceived global issues were more important to be highlighted compared to the local issues, which local issues involve limited numbers of population. The relationship of SD and global issues is very significant, where many issues such as security, peace and trade, hunger, shelter and water are discussed internationally (Jabareen, 2004).

Theme II, Conceptualizing sustainability into the engineering designs

Theme II represents the conceptualizing of SD concepts into an engineering design. The elements, which are categorized in the theme II, exemplify the integration of SD into the technical contexts and in abstract concepts. The elements are the holistic approach/integrative approach towards sustainability and the concepts of green/ecology technology. The Theme II includes the elements that are more complex, interdisciplinary oriented and high level of abstraction. The elements require students to interconnect various perspectives and approaches of SD. At the same time, the elements also require students to interrelate the elements of SD with technical perspective. Therefore, we proposed that students could gain a lot on their understanding if they could apply the SD concept in their engineering design.

Theme II – Sustainability competencies

The approach in dealing with engineering problems or issues in any levels of engineering processes for sustainability is significantly pointed to holistic approach or integrative approach, and could also called as systemic approach. In this paper, the holistic approach can be divided into two contexts; the first context is more concern on the planning and management for SD. Where Jabareen (2004) in his study had relates SD with the integrative management metaphor. *"This metaphor represents the sustainable development's integrative view of the aspects of social development, economic growth and environmental protection. It is believed that in order to achieve sustainability and ecological integrity,… we need an integrative and holistic management approach"*. The second context however is more concerns on the process of solving problems and manifesting the solutions. Boyle and Coates (2005) outlined pragmatic ways of solving problems holistically for engineer by creating *"solutions based primarily on human needs and ecosystem viability rather than the availability of technology or technological method"* and they added *"an integrated systems, or an overall holistic, approach shall be taken including all stakeholders and the environment when attempting solve problems. Rather than focusing solely on the technology aspects, and solving one problem at the expense for another,…"*.

The concept of green or ecology technology was clearly defined by Jabareen (2004) with his Eco-form metaphor. The metaphor, as he stated, *"represents the ecologically desired form of urban spaces and other human habitats. A key strand of research into sustainability strategies has focused on ecological design …. Sustainable design aims to create eco-forms, which are energy efficient and designed for long life"* (Jabareen, 2004). In practices in fact, based on table 1, eight out of twenty-five courses that integrate sustainability were included the concept of green or ecology technology as a part of the learning objectives. For instance, the students are aimed to propose a solution to improve energy efficiency for their university (course-L), and in another engineering course, students are expected to be able to explore the engineering methods based on the principles of sustainable building/design (course-U).

Theme III, Valuing sustainability in the engineering justification

Theme III includes the issues related to environment, resources and eco-system, social rights/value, social equity, citizenry, economic and stakeholders. These elements are predominantly categorized as non-technical contexts and concrete concepts for engineers. The Theme III encompasses the elements of sustainability that are more complex and more often create conflicts when it comes into implementation compare to the Theme I and the Theme II. In order to understand these elements, students not only learning on the factual knowledge and conceptual knowledge but experiencing and employing the elements into engineering process i.e. an evaluation process. Valuing these elements in any engineering evaluation process can be a huge challenge to engineering students and even engineers. However, these elements are crucial to be put in consideration of the engineers to justify their decisions. We proposed that these elements are integrated in engineering curricula and designed therefore students could value it in their engineering justification.

Theme III – Sustainability competencies

Environmental issues are the origins of the concept of SD. The knowledge of environmental management i.e. waste and water management always has been included in many debates either in the principles perspective or pragmatic point of views. Environment and environment management must be value together with economic development (Manion, 2002). Engineers must strive to prevent waste (Abraham and Nguyen, 2003), improve the quality of environment by maximizing the use of alternative materials and at the same time minimizing waste (Fenner et al, 2004). For Boyle and Coates (2005), engineers have to be firm in dealing the environmental issues. They suggested engineers have to *"eliminate all waste products, minimize or eliminate the use of hazardous material and reduce the use of materials and chemical that can accumulate in the environment"*. Besides the knowledge of environmental management, issues related to the resources and eco-systems are also in the heart of sustainability debates. The resources and eco-systems, also known as natural capital (Fenner et al. 2004; Jabareen, 2004), is not the only driver of sustainability but it also include other elements of sustainability (Fenner et al. 2004). Constantly natural capital and environmental issues are referred to the criteria in sustainability either in engineering practices or in engineering education.

On the other hand, the aspect of social perspectives in engineering education practices are less integrated or undervalued. Based on the Table 1, only seven out of twenty-five, integrates social perspectives i.e. social rights/values, social equity, citizenry and culture, into engineering courses. Frequently, the social perspectives are included not in the whole cycle of engineering processes but mostly evaluated as the end-of-pipe of analysis, i.e. social impact analysis and consumer satisfaction analysis. The acceptance of social values in SD in the level of principles and concepts is always sufficiently discussed and represented. All the principles, based on Table 1, include the elements of social rights/value, social equity, culture and citizenry as criterion to achieve sustainability. The issues evolved in social rights/values encompassed protection of human health and well-being (Abraham and Nguyen, 2003), public participation and involvement in engineering decisions (Fenner et al. 2004), relationships with technologies (Bell, 2011), social safety and legal (International Engineering Alliances, 2009), and the interaction of engineers with society (Barcelona Declaration, 2004). Therefore, *"the education that engineers will obtain through sustainability engineering will provide them with a better understanding of systems and processes and the roles of business and government in society" (*Taoussanidis and Antoniadou, 2006).

Another undervalued criterion that is presented in this paper is economical aspect. The teachers perceived the economic aspects as a driver for engineering knowledge, fields and practice for a long time. Economic aspects somehow play its role in shaping and limiting the SD; it is frequently placed before the issues related to SD unless it is satisfied. However, the relationship between economic aspects and SD concepts usually interpreted in an engagement of stakeholders. Engagement of stakeholders in engineering processes will give different views, perceptions, knowledge and skills (Dodds and Venables, 2005). Engineers have to actively engage with stakeholders as well as communities (which are part of stakeholders) in developing engineering solutions (Abraham and Nguyen, 2003). Findings from interview session with teacher shows that it is important for engineers to satisfy the needs and criteria set by stakeholders. In fact, from the finding, most stakeholders nowadays have showed their commitments and they have driven the implementation of sustainability in work places but not in the context of engineering education. Table 1, has demonstrated the number of courses that integrate 'stakeholders' into engineering is significantly low. The finding also has been highlighted back than in 2006, where the study stated that, *"…engineers remain ill-prepared to take on "extra-mural" responsibility - that is, responsibility in relation to key stakeholders in the wider society or the firm's geographical context"* (Taoussanidis and Antoniadou, 2006).

Theme IV, Implementing sustainability into the engineering solutions

Theme IV represents the implementation of SD concepts into the engineering solutions. The Theme IV encompasses the elements such as environmental assessments, quality in engineering as well as green or ecology technology. The criteria of this theme predominantly focus on integrating elements of sustainability into technical contexts and concrete concept. These elements also could be categorized as procedural knowledge. The knowledge that requires students have to experience how to apply and understand where to use it. Thus by implementing the knowledge such as environmental assessments in engineering solutions, students will obtain the knowledge efficiently and gain the skills of employing the knowledge into engineering contexts.

Theme IV – Sustainability competencies

Environmental assessments are acceptably having a strong relationship with environmental management and constantly relate to the technical part of sustainability, where tools and instruments are applied to assess the impact of engineering technology toward the environment. These assessments i.e. environmental impact assessment, life-cycle analysis, risk assessment need to be trained to engineers and these assessments part need to be considered as a part of engineering design (Taoussanidis and Antoniadou, 2006). The engineers also suggested *"….use system analysis, and integrate environmental impact assessment tools"* and *"Use life cycle thinking in all engineering activities"* (Abraham and Nguyen, 2003). Assessing the environment also become more important when it is assessed and translated into monetary-valued, this is defined by Dodds and Venables (2005), as a cost or compensation charge. The importance of assessing environment was further explained as stated, *"there is essential link between sustainable development and monetary valuations of the environment in terms of willingness to pay (WTP)"* (Turner, 2005).*"For some years now, engineering curricula have been increasingly taking into account the "intra-mural" responsibility of the firm, which involves issues of quality, hygiene, safety, …."* (Taoussanidis and Antoniadou, 2006). This 'intramural' responsibility is apparently related to the quality in engineering creation, which we combined issues of hygiene and safety as well as product efficiency, wide scales technologies and systems. The quality of engineering creation continues to be part of engineering responsibility, and we perceived it as a part of SD.

Conclusions

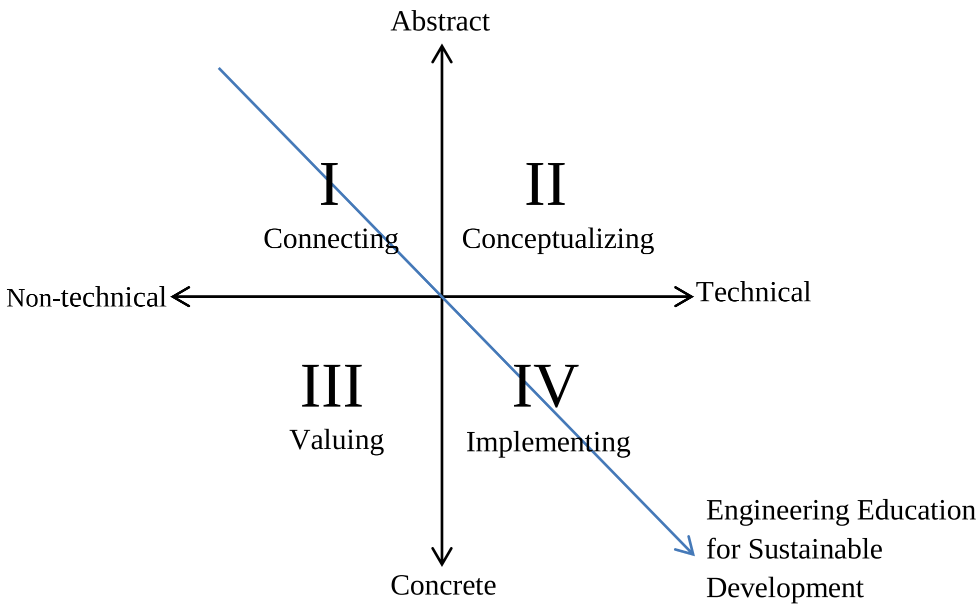

Figure 2: Steps to engineering education for sustainable development

The key sustainability themes and competencies are concluded as illustrated in Figure 2. By integrating the elements of sustainability which are represented by the themes I, II, III and IV, the themes are able to transform the traditional engineering education into engineering education for SD. These themes also signify the integration of SD in engineering education could affect the engineering curricula and the educational philosophy of engineering education. The direction of engineering education is driven not only by the stakeholders (universities and industries) but it reflects the whole concept of SD.

The integration of the themes also can be interpreted as steps i.e. I-II-III-IV in achieving the final goal. However, to accommodate a wide range of engineering fields i.e. electrical engineering, chemical engineering, biomedical engineering, we would suggest the steps arrangement of the key sustainability themes have to be adapted into the context, e.g. instead of applying I-II-III-IV, it is also possible I-III-II-IV, or other form of arrangement where the theme II and III are interchangeable and possible for repeatable. Future researches in extending sustainability competencies are recommended in a way to provide a comprehensive guideline for designing sustainability courses.

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